

10720839 IN SITU SUBSTRATE TEMPERATURE MONITORING

Type	L#	Hits	Search Text	DBs	Time Stamp	Comments
BRS	L1	1	10/608,091	US-PGPUB; USPAT	5/18/05 14:27	in IDS.
BRS	L2	60	(US-20010014111-\$ or US-20020048311-\$ or US-20030070758-\$ or US-20030080112-\$ or US-20040261721-\$).did. or (US-4262035-\$ or US-4854727-\$ or US-4880314-\$ or US-4890245-\$ or US-4913790-\$ or US-4919542-\$ or US-4969748-\$ or US-4984902-\$ or US-5021980-\$ or US-5156461-\$ or US-5180226-\$ or US-5225245-\$ or US-5255286-\$ or US-5388909-\$ or US-5508934-\$ or US-5549756-\$ or US-5568978-\$ or US-5597609-\$ or US-5690429-\$ or US-5703342-\$ or US-5743644-\$ or US-5755511-\$ or US-5806980-\$ or US-5820261-\$ or US-5823681-\$ or US-5875416-\$).did. or (US-5902504-\$ or US-6004029-\$ or US-6056433-\$ or US-6062729-\$ or US-6072163-\$ or US-6080969-\$ or US-6086245-\$ or US-6106148-\$ or US-6116779-\$ or US-6132081-\$ or US-6159607-\$ or US-6164816-\$ or US-6179466-\$ or US-6190037-\$ or US-6191399-\$ or US-6200023-\$ or US-6283630-\$ or US-6299346-\$ or US-6416890-\$ or US-6481886-\$ or US-6507007-\$ or US-6561694-\$ or US-6575622-\$ or US-6596973-\$ or US-6616331-\$ or US-6666577-\$ or US-6703592-\$).did. or (US-6798036-\$ or US-6799888-\$).did.	US-PGPUB; USPAT	5/18/05 14:47	tagged so far.
BRS	L4	25	("6514376" "6605955" "6635117" "4919542" "5200023" "5388909" "5467732" "5660472" "5683180" "5746513" "5755511" "5769540" "5848842" "5967661" "5996415" "6062729" "6082892" "6112595" "6174080" "6179466" "6182510" "6481886" "5568978" "5490728" "5775808").PN.	US-PGPUB; USPAT	5/18/05 14:42	cited in IDS in THIS application by Applicant.
BRS	L6	2	4 and 3	US-PGPUB; USPAT	5/18/05 14:43	already cited.
BRS	L7	5	4 and 2 not 3	US-PGPUB; USPAT	5/18/05 14:43	browse.
BRS	L3	12	("6191399" "5225245" "6062729" "6116779" "6106148" "4854727" "6575622" "5823681" "6283630" "20010014111" "5021980" "4919542").PN.	US-PGPUB; USPAT	5/18/05 14:47	cited in 892 previously.
BRS	L8	25	5583737	US-PGPUB; USPAT	5/18/05 14:48	browsed - cited in one of above patents.
BRS	L9	18	4 not 3 not 2 not 8	US-PGPUB; USPAT	5/18/05 15:54	browsed - removed duplicates.
BRS	L10	20	5 not 4 not 3 not 2 not 8	US-PGPUB; USPAT	5/18/05 15:54	no duplicates - browsed these - see next.. mostly chunks.
BRS	L5	20	("5192849" "5310453" "5382311" "5609720" "5671116" "5675471" "5835334" "6077357" "6083344" "6108189" "6179921" "6182602" "6189483" "6231776" "6310755" "6373681" "6377437" "6378600" "6394797" "6451157").PN.	US-PGPUB; USPAT	5/18/05 15:55	cited in IDS in related application 10/608,091 cited in IDS.

Type	L#	Hits	Search Text	DBs	Time Stamp	Comments
IS&R	L11	488	((374/1) or (374/2)).CCLS.	US-PGPUB; USPAT	5/18/05 16:05	
IS&R	L11	1480	((374/120) or (374/126) or (374/127) or (374/147) or (374/141)).CCLS.	US-PGPUB; USPAT	5/18/05 16:05	
IS&R	L13	1833	((427/8) or (427/585)).CCLS.	US-PGPUB; USPAT	5/18/05 16:06	
IS&R	L11	842	(438/16).CCLS.	US-PGPUB; USPAT	5/18/05 16:08	
IS&R	L15	408	((356/43) or (356/45)).CCLS.	US-PGPUB; USPAT	5/18/05 16:07	
BRS	L17	28	(12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/18/05 16:08	
BRS	L18	73	(13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/18/05 16:08	
BRS	L19	50	(14 not 13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/18/05 16:10	
BRS	L18	19	11 and @pd>"20041209"	US-PGPUB; USPAT	5/18/05 16:11	update
BRS	L20	2	(15 not 14 not 13 not 12 not 11) and @pd>"20041209"	US-PGPUB; USPAT	5/18/05 16:18	update
BRS	L22	0	17 and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/18/05 16:19	
BRS	L23	2	17 and plasma	US-PGPUB; USPAT	5/18/05 16:19	update
BRS	L21	25	(18 or 19) and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/18/05 16:19	update
IS&R	L24	528	(427/535).CCLS.	US-PGPUB; USPAT	5/18/05 16:44	
IS&R	L25	269	(438/9).CCLS.	US-PGPUB; USPAT	5/18/05 16:45	
BRS	L26	786	24 or 25	US-PGPUB; USPAT	5/18/05 16:45	
BRS	L27	1	24 and 25	US-PGPUB; USPAT	5/18/05 16:45	BROWSED
BRS	L28	529	26 and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/18/05 16:46	
BRS	L29	24	28 and (chuck or susceptor or pedestal) AND CALIBRAT\$4	US-PGPUB; USPAT	5/18/05 16:47	BROWSED
IS&R	L30	810	(374/179).CCLS.	US-PGPUB; USPAT	5/18/05 17:11	
IS&R	L31	509	(374/121).CCLS.	US-PGPUB; USPAT	5/18/05 17:11	
BRS	L32	30	(30 or 31) and ((plasma with wafer) or (plasma with substrate))	US-PGPUB; USPAT	5/18/05 17:12	

KEY WORDS:

IPC(7) Classification:	XREF?	CLASS 374:	
update	or	374/1	
update		374/2	
update		374/120	
update		374/126	
update		374/127	
update		374/147	
update	XR	374/141	
today MAY 16	XR	374/179	
today MAY 17	XR	374/121	

		CLASS 392/	
		392/416	

		CLASS 118/	
		118/724	
		118/725	

		CLASS 356	
update		356/43	
update	XR	356/45	

392/418

		438/9	... Plasma etching
		438/14	WITH MEASURING OR TESTING
		438/16	. Optical characteristic sensed
		438/485	.. Deposition utilizing plasma (e.g., glow discharge, etc.)
		438/798	. Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)
		438/907	CONTINUOUS PROCESSING
		438/909	CONTROLLED ATMOSPHERE

		356/43	OPTICAL PYROMETERS
		356/45	. Plural color

update	XR	427/8	MEASURING, TESTING, OR INDICATING
		427/165	.. Glass
		427/166	... Vapor depositing
		427/573	... With heated substrate
update		427/585	. Chemical vapor deposition (e.g., electron beam or heating using IR, inductance, resistance, etc.)
today MAY 16		427/535	... Plasma (e.g., cold plasma, corona, glow discharge, etc.)

		CLASS 438	
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		438/5	INCLUDING CONTROL RESPONSIVE TO SENSED CONDITION
		438/6	. Interconnecting plural devices on semiconductor substrate
		438/7	. Optical characteristic sensed
		438/8	.. Chemical etching
today MAY 16	XR	438/9	... Plasma etching
		438/14	WITH MEASURING OR TESTING
		438/15	. Packaging (e.g., with mounting, encapsulating, etc.) or treatment of packaged semiconductor
update	XR	438/16	. Optical characteristic sensed
later		438/798	. Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)
later		438/485	.. Deposition utilizing plasma (e.g., glow discharge, etc.)

		CLASS 219/	
		219/497	ask ? later
		219/505	ask ? later
		219/390	ask ? later

only
Accident my her
Joe Pelkan
see MAY/
PARCHEL

Pruchnic, Stanley

Subject: Class 438 SEMICONDUCTOR DEVICE MANUFACTURING: PROCESS
Status: Not Started
Percent Complete: 0%
Total Work: 0 hours
Actual Work: 0 hours
Owner: Pruchnic, Stanley

438/5 INCLUDING CONTROL RESPONSIVE TO SENSED CONDITION

438/6 . Interconnecting plural devices on semiconductor substrate

438/7 . Optical characteristic sensed

438/8 .. Chemical etching

438/9 .. Plasma etching

438/14 WITH MEASURING OR TESTING

438/15 . Packaging (e.g., with mounting, encapsulating, etc.) or treatment of packaged semiconductor

438/16 . Optical characteristic sensed

=====

438/485 .. Deposition utilizing plasma (e.g., glow discharge, etc.)

438/758 COATING OF SUBSTRATE CONTAINING SEMICONDUCTOR REGION OR OF SEMICONDUCTOR SUBSTRATE

438/795 RADIATION OR ENERGY TREATMENT MODIFYING PROPERTIES OF SEMICONDUCTOR REGION OF SUBSTRATE (E.G., THERMAL, CORPUSCULAR, ELECTROMAGNETIC, ETC.)

438/796 . Compound semiconductor

438/797 .. Ordering or disordering

438/798 . Ionized irradiation (e.g., corpuscular or plasma treatment, etc.)

Pruchnic, Stanley

Subject: Class 427 COATING PROCESSES

Status: Not Started

Percent Complete: 0%

Total Work: 0 hours

Actual Work: 0 hours

Owner: Pruchnic, Stanley

Class 427 COATING PROCESSES

427/8 MEASURING, TESTING, OR INDICATING

427/569 . Plasma (e.g., corona, glow discharge, cold plasma, etc.)

427/570 .. Utilizing plasma with other nonionizing energy sources

427/571 ... With magnetic enhancement

427/572 ... Light as energy source

427/573 ... With heated substrate

427/585

. Chemical vapor deposition (e.g., electron beam or heating using IR, inductance, resistance, etc.)

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427/162 OPTICAL ELEMENT PRODUCED

427/163.1 . Polarizer, windshield, optical fiber, projection screen, or retroreflector

427/163.2 .. Optical fiber, rod, filament, or waveguide

427/163.3 .. Projection screen

427/163.4 .. Retroreflector (e.g., light reflecting small spherical beads, etc.)

427/164 . Transparent base

427/165 .. Glass

427/166 ... Vapor depositing

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DRAFT notes

US 6191399 B1 (Van Bilsen; Frank B. M.)

VAN BILSEN, as described in the previous Office Action, discloses, in a CVD reactor 10, a wafer support structure 18, including a wafer holder 20, and wafer 16. A non-contact temperature sensor 21 such as a pyrometer is in the chamber, as well as a thermocouple 28. The support structure includes a spider 22, however, VAN BILSEN does not disclose a chuck as claimed by Applicant. Thermocouple readings are used to periodically calibrate the pyrometer (Fig. 4; Col. 7). VAN BILSEN's assumption (Col. 7, Lines 25-32) that thermocouple 28 is more reliable than the pyrometer is not generally valid for the case of a working plasma chamber, that is, in use while processing a substrate. VAN BILSEN's method and device would not function as claimed by Applicant in the presence of a plasma. Therefore, one having ordinary skill in the art would not have found it obvious to use the method and device as claimed by Applicant in a plasma processing system.

Importantly, VAN BILSEN requires the temperature measurement using the thermocouple to be done at the same time as the temperature measurement using the pyrometer, during a steady state portion of the recipe (Col. 7, Lines 17-24).

VAN BILSEN teaches away from the claimed invention which requires, in a plasma processing system, the method measuring a first chuck temperature using a physical measuring device in thermal contact with said chuck and in the absence of a plasma in said plasma processing system; and also determining a temperature of said substrate during plasma processing, wherein said plasma is present in said plasma processing system as claimed by Applicant in Claim 1 and in Claim 25.

THEVENARD (IDS cite No. 33) discloses a method for calibrating a spectroscopic (infrared) wafer temperature measurement and states the application of intended use on Page 44: "We are ultimately thinking of a device that could be integrated in the plasma chamber of an etching tool (for instance) and that would measure temperature in real time."

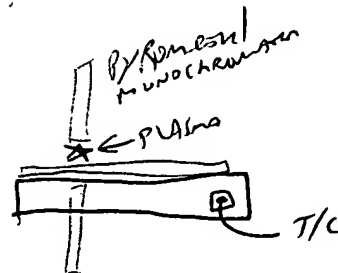
THEVENARD recognizes the need, but does not provide the solution of the problem.

HIRSCHER (IDS cite No. 27) "This backside gas injected at a defined gas pressure and at a certain gap of the wafer to the pedestal - improves the heat transfer dramatically."

DRS vs. Other Techniques (IDS cite No. 29) Of thermocouples, "Disadvantages: In order to work, the thermocouples must make mechanical contact with the sample. In cases where the sample is rotating or the sample is immersed in a hostile environment (such as harsh chemicals, plasma discharge, etc.) then thermocouples cannot be used. As well, in many cases, it is not acceptable to touch the surface of the device during processing. In addition, care must be taken to insure that the thermocouples do not conduct significant heat away from the sample."

Examples of some illustrative chambers are described in U.S. Pat. No. 5,583,737, issued Dec. 10, 1996; U.S. Pat. No.

Amendment submitted in response
to Office Action mailed 12/15/2004
U.S. Pat App. No. 10/720,839
4/15/2005
Page 2



AMENDMENTS TO THE CLAIMS:

Claim 1 (currently amended): In a plasma processing system, a method of determining the temperature of a substrate, comprising:

positioning said substrate on a substrate support structure, wherein said substrate support structure includes a chuck;

creating a temperature calibration curve for said substrate, said temperature calibration curve being created by measuring at least a first substrate temperature with an electromagnetic measuring device, and measuring a first chuck temperature with a physical measuring device in thermal contact with said chuck during a first isothermal state of said substrate, in the absence of a plasma in said plasma processing system;

employing a measurement from said electromagnetic measurement device and said temperature calibration curve to determine a temperature of said substrate during plasma processing, wherein said plasma is present in said plasma processing system.

Claim 2 (original): The method of claim 1, further including the step of measuring a second substrate temperature with said electromagnetic measuring device, and measuring a second chuck temperature with said physical measuring device during a second isothermal state.

Claim 3 (original): The method of claim 1, wherein said substrate is positioned between said plasma and said electromagnetic measuring device.

Claim 4 (original): The method of claim 1, wherein said substrate support structure further comprises said physical temperature measuring device.

Claim 5 (original): The method of claim 1, where said electromagnetic measuring device comprises a narrow-band pyrometer.

Claim 6 (original): The method of claim 1, where said electromagnetic measuring device comprises a monochromator.

OR-374/1

XR 374/121

XR 374/179

XR 374/141

XR 356/45

XR 427/8

XR 438/9, 16

118/

orepelham

219/390 [general with pro 1.5/1/1/1 - in 1/1/1/1 (x1/1/1/1)]

392/

NOT REQUIRED

is the "second radiation constant", and L_1, L_2 are "effective wavelengths" corresponding to λ_1, λ_2 respectively. The effective wavelength of a thermometer is the wavelength of an equivalent (ideal) monochromatic thermometer - i.e. one which matches the calibration function of the actual thermometer over the temperature range of interest.

Brightness temperatures are the temperatures one derives directly from the thermometer signals S_1, S_2 (using Planck's Law) without any correction for emissivity effects.

Equations 1', 2' are just equations 1, 2 written in a different way - i.e. where T_1, T_2 are taken to be the measurands rather than S_1, S_2 . Taken with equation 3, equations 1', 2' form a three-equation, three-unknown system which can be solved for true temperature T .

This representation is useful in practice where the thermometer directly outputs brightness temperatures rather than "radiance" signals S_1, S_2 .

If we take equations 1', 2' together with equation 5 we get, with some manipulation:

$$1/T = (A + 1) \cdot 1/T_1 - A \cdot 1/T_2 + B \quad (6)$$

where $A = b \cdot L_1 / (L_2 - b \cdot L_1)$

and $B = A \cdot L_2 \cdot \ln a / c \cdot 2 \cdot b$

and we can solve for T from measured T_1, T_2 if we know A and B .

We can get the A and B needed in equation 6 in a number of ways, for example we could make a theoretical analysis of the relationship between E_1 and E_2 , hence derive a, b and hence A, B , or we could, similarly, make an empirical study of how E_1 relates to E_2 , hence derive a, b and hence A, B .

However, a very direct and effective way is to simply record T_1, T_2 in the measurement application over a period of time while also taking "reference" values of true temperature T using, for example, a contact thermometer.

A plot of $1/T - 1/T_1$ versus $1/T_1 - 1/T_2$ is formed called a "1/T" plot and then a best straight line fit to the data is made, whence the slope and intercept of the line give directly A and B respectively.

An important point to recognise is that a straight line relation in the $1/T$ plot is not essential to the method. A straight line follows from equation 6, which follows from equation 5 - i.e. the log-linear assumption. However, provided the empirical data forms a single-valued relation in the $1/T$ plot then the plot can be used directly to relate T to measured T_1, T_2 without any a prior assumption about the form of the $E_1 = f(E_2)$ relation.

Thus, we have a purely empirical method: T_1, T_2, T data is collected (e.g. during system commissioning) and points entered into a $1/T$ plot. Any promising function is then used to fit the data and hence permit calculation of T from future measured

T_1, T_2 .

This approach which is also described in GB-A-2160971 works successfully and it is found that once an empirical $1/T$ relation is established it is stable and may be used over many months without adjustment.

For a metal stream, the situation can be more complex. We have found that a $1/T$ relation can be established which correctly accounts for the ($E_1 = f(E_2)$) behaviour of one interference (e.g. cavitation) but that other interferences occur, in a fluctuating manner, which are not correctly described by this $1/T$ relation.

If one interference is dominant then the result is a predominance of readings that fall on a line (not necessarily straight) in the $1/T$ plot but with a scatter of readings on either side of this line.

One can exploit the fast response of the thermometer to take readings in large ensembles (e.g. a thousand T_1, T_2 values in a one second interval). This allows one to use internal consistency to select those readings which are subject to only the single (modelled) interference and reject those that are subject to multiple interferences.

This can work as follows:

From theoretical and/or empirical studies, it is decided that interference "X" is dominant. We further establish a $1/T$ relation which models interference "X".

Conveniently (but not necessarily) let us assume that this $1/T$ relation turns out to be a straight line - i.e. our modelling gives us A and B values as per equation (6).

Initially, the computer determines from the sensed intensity pairs S_1, S_2 , equivalent radiance pairs T_1, T_2 using a conventional "linearisation" routine. In this example, illustrated in the flow diagram form in Figure 4, the computer 12 then computes from each of the 1000 T_1, T_2 pairs a temperature T using equation 6 (step 30). The values of T are then grouped into respective temperature ranges, for example 5 celsius intervals, by incrementing respective counts depending upon each value of T which is obtained in step 30. (Step 31.)

This results in a set of counts, an example of which is indicated graphically in Figure 5. In this Figure, seven temperature ranges are defined centred on respective temperatures (defined along the horizontal axis) while the number of values falling within each temperature range is plotted on the vertical axis. In a step 32, the computer 12 determines the temperature range with the most T values, in this case temperature range 3, and outputs (step 33) to a display or printer (not shown) the mean temperature value of that temperature range. Alternatively, the value may be converted back to analogue form and used for control purposes or the like. In other methods, as described above, account





US005549756A

United States Patent [19]

Sorensen et al.

[11] Patent Number: 5,549,756

[45] Date of Patent: Aug. 27, 1996

[54] OPTICAL PYROMETER FOR A THIN FILM DEPOSITION SYSTEM

[75] Inventors: Carl A. Sorensen, Morgan Hill;
Wendell T. Blonigan, Fremont, both of Calif.

[73] Assignee: Applied Materials, Inc., Santa Clara, Calif.

[21] Appl. No.: 190,421

[22] Filed: Feb. 2, 1994

[51] Int. Cl.⁶ C23C 16/00[52] U.S. Cl. 118/715; 118/725; 118/728;
118/723 E; 118/663; 118/666; 118/712;
118/713; 250/338.1; 374/120; 374/121;
374/127[58] Field of Search 118/663, 666,
118/712, 713, 725, 728, 723 R, 723 IR,
723 E, 715; 250/341.6, 338.1; 374/120,
121, 127

[56] References Cited

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156327	7/1991	Japan	118/666
70291	3/1993	Japan	118/666

OTHER PUBLICATIONS

Japio Abstract Japan Pat. No. 3-156327, Fujitsu Ltd.

Primary Examiner—R. Bruce Breneman

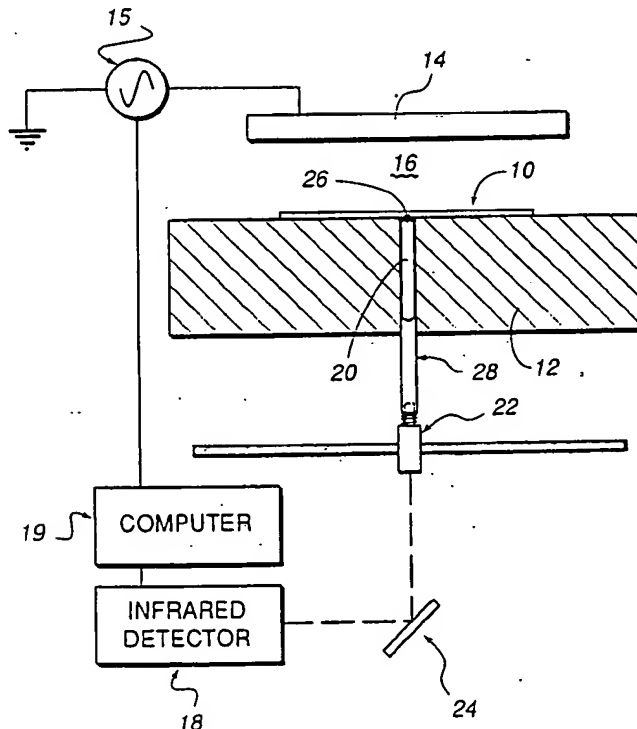
Assistant Examiner—Jeffrie R. Lund

Attorney, Agent, or Firm—Loeb & Loeb LLP

[57] ABSTRACT

A temperature measurement system for use in a thin film deposition system is based on optical pyrometry on the backside of the deposition substrate. The backside of the deposition substrate is viewed through a channel formed in the susceptor of the deposition system. Radiation from the backside of the deposition substrate passes through an infrared window and to an infrared detector. The signal output by the infrared detector is coupled to electronics for calculating the temperature of the deposition substrate in accordance with blackbody radiation equations. A tube-like lightguide shields the infrared detector from background radiation produced by the heated susceptor.

32 Claims, 2 Drawing Sheets



Sorenson

5,549,756

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the susceptor 12 from the backside of the deposition substrate 10. The lightguide 28 is preferably sufficiently smooth on its inner surface so that relatively little of the radiation emitted by the deposition substrate 10 is absorbed or reflected back toward the deposition substrate.

The lightguide 28 may be a ceramic tube and, in particular, may be an alumina tube. Alumina is a suitable material for use because it is stable over a wide range of temperatures and environmental conditions and because its elemental constituents, aluminum and oxygen, are found elsewhere in the processing environment. For example, the susceptor 12 is typically formed from aluminum, and glass deposition substrates typically include oxygen as an elemental constituent. It is generally advisable to not introduce different types of material into the thin film deposition environment to avoid the dangers of contamination or undesired reaction. Potential contamination problems may arise unexpectedly due to the harsh chemical environment of the deposition chamber and because of the very energetic reactions facilitated by the plasma. It is therefore simplest to only use materials that are already present in the deposition chamber environment so that no new contamination problems arise.

Because it is used in the chemically reactive environment of the deposition chamber, the emissivity of the lightguide may vary over time. Process gases from the plasma region may reach the inner surface of the lightguide and react with the lightguide material, even if the process gases are present only in greatly reduced quantities. Thus, a variety of chemical reactions may occur over time, altering the chemical composition of the lightguide and consequently altering the optical properties of the lightguide. For the purposes of the pyrometric system described herein, one of the most important of the optical properties that might change over time is the emissivity of the lightguide. For example, if the lightguide were formed from aluminum, prolonged exposure to some of the process gases used in thin film deposition might cause the inner surface of the lightguide to be converted into aluminum oxide. Aluminum oxide typically has a higher emissivity than does a polished piece of aluminum. Additionally, the chemical reaction which converts aluminum to aluminum oxide might cause the inner surface of the lightguide to become rougher, increasing the scattering of light from the walls of the lightguide. Similar chemical reactions or physical roughening may occur with other lightguide materials, as well.

If the optical properties of the lightguide, or any other optical component along the optical path from the backside of the deposition substrate to the infrared detector, vary over time, it may be preferable to periodically recalibrate the temperature measurement system. Calibration may be accomplished in a number of different ways. A deposition substrate may be fitted with a thermocouple or other thermometer to measure the actual temperature of the substrate for comparison with the pyrometric determined temperature. A different sort of recalibration may be performed to allow the pyrometric temperature measurements to be made as a differential measurement. For example, the background temperature measurement might be made by measuring the intensity of the background radiation when a "cold" glass substrate is moved into place on the susceptor. For the purposes of calibrating the temperature measurement system, a "cold" glass substrate is one having a sufficiently low temperature that the blackbody radiation from the substrate is a negligible proportion of the total intensity collected by the infrared detector. In practice, a room temperature substrate may be sufficiently cold to perform background measurements. In such a background measurement, the primary

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purpose of the cold glass substrate is to shield the infrared detector from any blackbody source disposed above the usual substrate position. Either the level of background radiation or the apparent background temperature can be used as a background radiation reference signal. The background reference signal is then stored in a memory either within the calculation electronics or in the deposition system's computer 19. Subsequent pyrometric measurements are made relative to the previously determined background radiation reference signal. In other words, the background radiation is "subtracted off" from the pyrometric measurements. The background measurement can be made as often as is necessary to maintain the accuracy of the temperature measurement.

Both aluminum and alumina may be suitable lightguide materials, but there are tradeoffs associated with the choice of one material or the other. For example, an aluminum tube having a highly polished inner surface is highly reflective and consequently is expected to have a substantially lower emissivity than an alumina tube. The use of an aluminum tube would therefore decrease the amount of background signal produced by the blackbody radiation from the walls of the lightguide. However, an alumina lightguide has greater chemical stability, and it is less likely that the optical properties of the lightguide will vary over time. Accordingly, the choice of lightguide material will often depend on the exact nature of the chemicals used for the thin film deposition. As discussed above, it is preferable that the lightguide be formed of a material already present in the deposition environment. It is, of course, possible to use a different material for the lightguide, if the material is chosen so as to not produce unacceptable contamination of the thin films deposited in the system.

A second design consideration in choosing the lightguide material is that the walls of the lightguide will conduct heat away from the deposition substrate. Such heat conduction can cause a local cold spot to develop on the surface of the deposition substrate. The surface of such a cold spot might have a temperature slightly lower than surrounding regions of the deposition substrate, and might produce measurably different electrical properties in the films deposited in that region. Unacceptable uniformity variations in the deposited thin films might result if the temperature drop at the surface of the substrate were sufficient to produce measurable differences in the properties of thin films deposited in that region. To reduce the amount of heat conducted away from the deposition substrate, the walls of the lightguide are preferably made as thin as possible so that the lightguide has as low of a thermal conductivity as possible, while still maintaining sufficient mechanical strength to survive vacuum pumping cycles within the deposition environment. To further reduce the amount of heat flow away from the surface of the deposition substrate, it is desirable to form the lightguide from a low thermal conductivity material. From this point of view, a ceramic tube is more desirable than an aluminum tube. However, because thermal conductance is a function of the cross sectional area of the lightguide and because an aluminum tube can have substantially thinner walls than a ceramic tube, an aluminum tube can be made to have a thermal conductance approaching that of a ceramic tube.

The lightguide is preferably physically isolated from the susceptor along almost all of its length to reduce the background radiation from the walls of the tube. Under some circumstances, however, the lightguide itself may be a part of the susceptor 12. For example, the susceptor 12 may be formed from aluminum, the optical emissivity of the alumi-

[0120] For a wafer having a temperature above about 300° C., these technical problems include the unknown emissivity of semiconductor wafer 160, and measurement errors caused by reflected background radiation. The unknown wafer emissivity causes large errors in temperature measurement because typical semiconductor wafer emissivities range from about 0.1 for metal films like copper to about 0.9 for oxides of certain thickness. Semiconductor wafer emissivity is a strong function of film type and thickness for both single- and multi-layer films deposited on both the front and backside of the semiconductor wafer 160. Emissivity is also a function of the measurement wavelength and radiation collection angles employed by radiometric system 10.

[0121] A preferred wafer temperature measurement method of this invention addresses sources of measurement error caused by unknown emissivity and reflected background radiation in processing applications that include a heated susceptor. Many semiconductor processing tools include one or more heated susceptors, which are commonly referred to as chucks, wafer holders, workpiece supports, or hot plates. Susceptors such as heated susceptor 162 are often manufactured from graphite that is typically coated with either silicon carbide or boron nitride. Susceptors may also be manufactured from aluminum, aluminum nitride, and silicon. The manufacture of susceptors, such as hot susceptor 162 is tightly controlled because its parameters directly impact the processing of semiconductor wafer 160. For example, hot susceptor 162 has a tightly controlled surface texture, finish, and coating(s) to control among other things, contamination, heat transfer, and gas flow.

[0122] The temperature of hot susceptor 162 is also tightly controlled during processing of semiconductor wafer 160, typically by employing closed loop feedback from sensors, such as a thermocouple 172 or a second radiometric system 174, either of which is coupled to a CPU 176. Other suitable temperature measuring devices include resistance temperature devices, platinum resistance thermometers, thermistors, and optical thermometers.

[0123] The semiconductor wafer temperature measurement method of this invention takes advantage of the tight control of the surface conditions and temperature of hot susceptor 162, which tight control provides known and reproducible radiation emissions from hot susceptor 162. The known amount of radiation emitted by hot susceptor 162 is employed as a stable radiation source for making precise reflectance measurements of semiconductor wafer 160.

[0124] Collection optics 12 of radiometric system 10 is positioned in and sensing radiation through an opening 164 in hot susceptor 162. Hot susceptor 162 emits emitted radiation 166, which reflects off semiconductor wafer 160 as reflected radiation 168 that enters collection optics 12, and is sensed by radiometric system 10. When semiconductor wafer 160 is initially loaded in a processing chamber, it is relatively cold and, therefore, emits very little radiation. At this time, while semiconductor wafer 160 is separated from hot susceptor 162 by a gap 170, most of the radiation sensed by radiometric system 10 is reflected radiation 168 originating from hot susceptor 162. Semiconductor wafer 160 is then moved toward hot susceptor 162, while radiometric system 10 makes multiple real-time measurements of reflected radiation 168. Because the amount of reflected

radiation 168 varies as gap 170 diminishes toward zero, radiometric system 10 senses information indicative of the reflectance and roughness of semiconductor wafer 160. Semiconductor wafer 160 typically comes to rest on hot susceptor 162 as shown in dashed lines.

[0125] A process tool, typically a robot, has a fixed geometry and moves semiconductor wafer 160 toward hot susceptor 162 in a very reproducible manner. This makes it practical to calculate the amount of emitted radiation 166 by using the Planck Blackbody equation, then based on this result, to calculate the reflectivity of semiconductor wafer 160. The emissivity of semiconductor wafer 160 can then be calculated using Kirchhoff's 1860 radiation law, which is expressed as:

$$1 - R = \epsilon \quad (1)$$

[0126] where R is the reflectivity, and ϵ is the emissivity.

[0127] Using Kirchhoff's law provides nearly 100 percent accurate and valid results because hot susceptor 162 is a very uniform and diffuse emitter, thereby illuminating semiconductor wafer 160 in a nearly hemispherical (all angles) manner, which is required for proper application of the law. Skilled workers understand that actual semiconductor wafers require only about a 50° total cone angle for reliable emissivity calculations when employing Kirchhoff's law.

EXAMPLE

[0128] FIG. 18 shows a semiconductor wafer processing apparatus 180 suitable for carrying out the temperature measurement method of this invention. A horizontal transporter 182 moves semiconductor wafer 160 by its peripheral margins into position above and spaced apart from hot susceptor 162 by the distance of gap 170, which typically ranges from about 2.54 cm (1.0 inch) to about 0.0254 mm (0.001 inch). Note that horizontal transporter 182 does not substantially block the surface of wafer 160 from hot susceptor 162 or radiometric system 10. As wafer 160 is moved horizontally into position, cool semiconductor wafer 160 emits some emitted radiation 184, which is sensed by radiometric system 10. Emitted radiation 184 is initially small and increases when semiconductor wafer 160 is heated during subsequent lowering toward hot susceptor 162. Before lowering semiconductor wafer 160, emitted radiation 166 from hot susceptor 162 that is reflected by semiconductor wafer 160 as reflected radiation 168 provides a baseline radiation measurement for comparing with measurements taken during the subsequent downward motion of semiconductor wafer 160. Hot susceptor 162 typically has a predetermined temperature in a range from 70° C. or less to about 1,300° C.

[0129] A vertical transporter 186 lifts semiconductor wafer 160 off horizontal transporter 182, which moves out from under semiconductor wafer 160. Vertical transporter 186 then commences moving semiconductor wafer 160 toward hot susceptor 162, which movement time ranges from a fraction of a second to a few seconds. As semiconductor wafer 160 moves downward, its reflected emission 168 is measured by radiometric system 10 in real time as a function of diminishing gap 170. This relationship is employed to calculate the effective reflectivity of semiconductor wafer 160. This calculation employs the well-known relationship shown below in Eq. 2, which relates the effective or apparent emission to substrate emission when a

6,167,834 issued Jan. 2, 2001, U.S. Pat. No.

5,824,197, issued Oct. 20,

1998, and U.S. Pat. No.

6,254,328 issued Jul. 3, 2001, all of which are
incorporated herein by reference in their entireties.

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6,167,834

5,824,197

6,254,328



US005806980A

United States Patent [19]

Berrian

[11] Patent Number: 5,806,980

[45] Date of Patent: Sep. 15, 1998

[54] METHODS AND APPARATUS FOR MEASURING TEMPERATURES AT HIGH POTENTIAL

Primary Examiner—Diego F. F. Gutierrez
Attorney, Agent, or Firm—Curtis A. Vock

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[73] Assignee: Novellus Systems, Inc., San Jose, Calif.

[21] Appl. No.: 712,310

[22] Filed: Sep. 11, 1996

[51] Int. Cl.⁶ G01K 7/04; G01K 13/00;
G01K 1/14

[52] U.S. Cl. 374/179; 374/141; 374/152

[58] Field of Search 374/179, 141,
374/152

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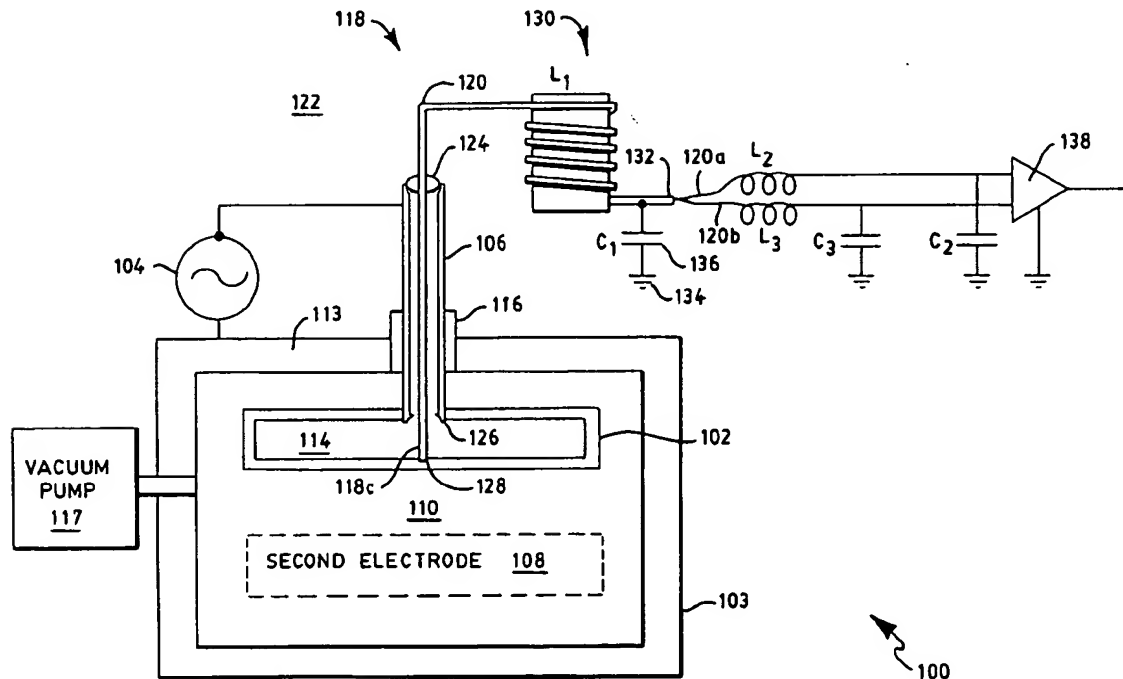
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ABSTRACT

A thermocouple is provided which measures the temperatures of structures at high RF potential, such as an RF electrode within a plasma CVD or plasma etch reactor. The thermocouple includes an outer conductive sheath that connects to the RF electrode at a first location, and a wire pair, connected to a second location of the RF electrode, that is used to sense the RF electrode temperature. The sheath—or a conductive member connected in circuit with the sheath—is wound into a coil to form an inductor with an impedance much greater than the impedance of the RF electrode. A large capacitor grounds the coil so that the thermocouple wires, extending through the sheath, and through and out of the coil, are available for diagnostic purposes. While RF current flows through the sheath, the wires experience the same magnetic field generated by the inductive coil, substantially grounding the thermocouple. Preferably, signal conditioning electronics remove any remaining DC bias voltages. In the case of a reactor for plasma CVD or etch, the thermocouple can be enclosed within a vacuum-sealed RF feedthrough that conducts the RF energy to the electrode.

29 Claims, 6 Drawing Sheets





US 20030029835A1

Cye

(19) United States

(12) Patent Application Publication
Yauw et al.

(10) Pub. No.: US 2003/0029835 A1

(43) Pub. Date: Feb. 13, 2003

(54) METHOD OF ETCHING ORGANIC
ANTIREFLECTION COATING (ARC)
LAYERS

(52) U.S. Cl. 216/67

(57) ABSTRACT

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(21) Appl. No.: 09/813,392

(22) Filed: Mar. 20, 2001

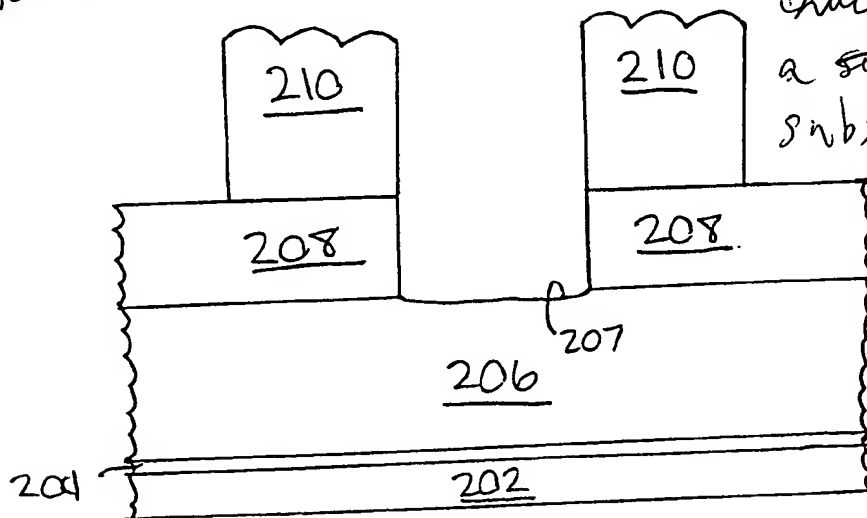
Publication Classification

(51) Int. Cl.⁷ C23F 1/00; B44C 1/22; C03C 15/00;
C03C 25/68

A two-step method of etching an organic coating layer, in particular, an organic antireflection coating (ARC) layer, is disclosed. During the main etch step, the organic coating layer is etched using a plasma generated from a first source gas which includes a fluorocarbon and a non-carbon-containing, halogen-comprising gas. Etching is performed using a first substrate bias power. During the overetch step, residual organic coating material remaining after the main etch step is removed by exposing the substrate to a plasma generated from a second source gas which includes a chlorine-containing gas and an oxygen-containing gas, and which does not include a polymer-forming gas. The overetch step is performed using a second substrate bias power which is less than the first substrate bias power. The first source gas and first substrate bias power provide a higher etch rate in dense feature areas than in isolated feature areas during the main etch step, whereas the second source gas and second substrate bias power provide a higher etch rate in isolated feature areas than in dense feature areas during the overetch step, resulting in an overall balancing effect.

X¹¹ is cited for disclosure of plasma etching 200

devices includes source gases, and using an electrostatic chuck for holding a ~~semiconductor wafer~~ substrate and includes



a chuck pedestal temperature probe 812. The substrate may be silicon or 204 glass, for example [9163].



US 20040208228A1

C1758

(19) **United States**(12) **Patent Application Publication**
Hashikura et al.(10) Pub. No.: **US 2004/0208228 A1**(43) Pub. Date: **Oct. 21, 2004**(54) **TEMPERATURE GAUGE AND CERAMIC
SUSCEPTOR IN WHICH IT IS UTILIZED****Publication Classification**(51) Int. Cl.⁷ G01K 1/00; G01K 7/00

(52) U.S. Cl. 374/179; 374/208

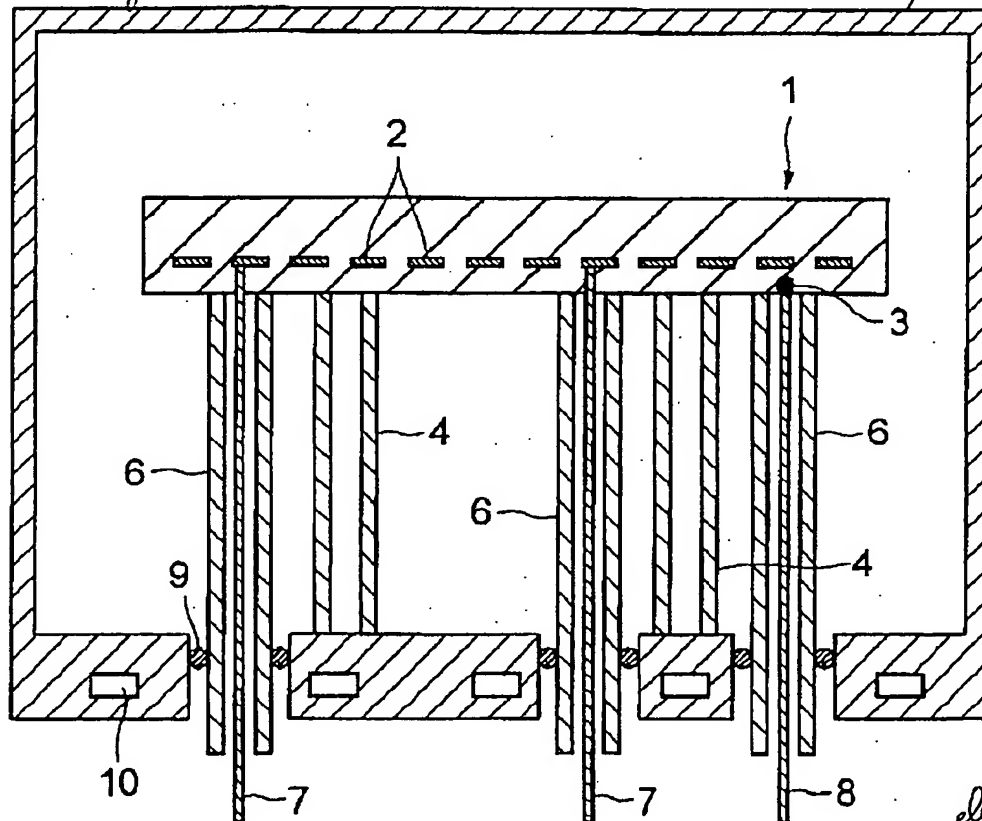
(75) Inventors: **Manabu Hashikura, Itami-shi (JP);
Hirohiko Nakata, Itami-shi (JP);
Masuhiro Natsuhara, Itami-shi (JP);
Akira Kuibira, Itami-shi (JP)**Correspondence Address:
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NISHINOMIYA-SHI, HYOGO 662-0035 (JP)**(73) Assignee: **SUMITOMO ELECTRIC INDUS-
TRIES, LTD., Osaka-shi (JP)**(21) Appl. No.: **10/605,519**(22) Filed: **Oct. 6, 2003**(30) **Foreign Application Priority Data**

Oct. 8, 2002 (JP) JP-2002-294399

(57) **ABSTRACT**

Temperature gauge, and ceramic susceptors and semiconductor manufacturing equipment utilizing the temperature gauge, in which the thermocouple may be easily replaced even if damaged, and in which heat from the temperature-gauging site is readily transmitted to the temperature-gauging contact, shortening time until the measurement temperature stabilizes. A temperature-gauging contact (12) in the tip of the thermocouple contacts, in an exposed-as-it-is state, a temperature-gauging site on a ceramic susceptor (1), and by means of a circular cylindrical-shaped retaining member (11) screwed into female threads in the ceramic susceptor (1) is detachably pressed upon and retained against the ceramic susceptor. Thermocouple lead lines (13), passing through a through-hole (14) in the retaining member (11), stretch from one end face to the other end face thereof. The retaining member may be provided with a flange having threaded holes and screwlocked into female screws in the ceramic susceptor.

"H" is cited for disclosure of an ~~embedded~~ ^athermocouple
embedded in a ⁵WAFER-holding



Susceptor
in a
plasma
processing
system.

H does not
disclose a
fairly
su best
the
combination
of embed.
T/C and
an

electro-magnetic
type T° measurement
device, as
claimed by AP1.



(43) Pub. Date: Dec. 30, 2004

made of the same material as the ceramic member 146 (e.g., alumina). The heat transfer member 48 is laterally separated from the inner ring 80 by a space 82. The electrostatic chuck 50 contacts the inner ring 80.

[0041] The electrostatic chuck 50 is preferably bonded to the heat transfer member 48 with a suitable adhesive material, such as an elastomeric material. The adhesive preferably includes a material, such as a metallic filler, to enhance its thermal conductivity to provide sufficient heat transfer between the electrostatic chuck 50 and the underlying heat transfer member 48. For example, the adhesive can include particles of at least one metal or metal alloy to enhance its conductivity.

[0042] As explained above, a large metallic cold plate (typically made of aluminum) can have a thickness of 1/4 inch or more and a corresponding large thermal mass. In contrast, the heat transfer member 48 preferably has a volume equal to about 5-10% of the volume of such large cold plate. Due to the significantly reduced volume of the heat transfer member 48, the amount of heat that needs to be removed from, or added to, the heat transfer member 48 to change its temperature by a given amount, is significantly reduced as compared to such a large cold plate. The heat transfer member 48 preferably can be heated and/or cooled at a rate of from about 0.25° C./sec to about 2° C./sec. In comparison, a large cold plate, which has a large thermal mass, provides a temperature change rate that may only be as high as about 1° C./min or less. The heat transfer member 48 preferably can be controlled to a temperature ranging from about -20° C. to about 80° C. during plasma processing.

[0043] Furthermore, due to the low thermal mass of the heat transfer member 48, the volumetric flow rate of liquid that needs to be supplied to the heat transfer member 48 to heat and/or cool the heat transfer member 48 to a desired temperature is significantly reduced as compared to the liquid flow rate needed to heat and/or cool a large cold plate having a large thermal mass.

[0044] A preferred embodiment of the substrate support 40 includes a liquid source 100, a heat transfer gas source 150 (FIG. 6), and a controller 200. As described above, the liquid source 100 (FIG. 2) supplies liquid to the flow passages in the heat transfer member 48. The liquid source 100 can comprise a thermoelectric chiller (e.g., a Peltier cooler), heat exchanger, or the like, to supply liquid at a selected temperature and/or flow rate to the flow passages. The liquid source 100 can comprise a suitable pump arrangement. The chiller or the like is preferably located close to the heat transfer member 48 to reduce the distance that the liquid flows from the liquid source 100, thereby reducing the liquid volume in the liquid path that needs to be heated or cooled, as well as reducing the response time of the liquid source.

[0045] The heat transfer gas source supplies heat transfer gas to the heat transfer gas passages. Heat transfer gas is flowed through the heat transfer gas passages, to the exposed surface of the electrostatic chuck 50, where the heat transfer gas is distributed via openings and/or channels (not shown) formed in the exposed surface to the interface 85 between the exposed surface and the backside of the substrate 70 (FIG. 6). A suitable heat transfer gas supply system that provides zone cooling of the exposed surface of a substrate

support is disclosed in commonly-assigned U.S. Pat. No. 5,609,720, which is incorporated herein by reference in its entirety. The heat transfer gas can be any gas having heat transfer capabilities to sufficiently transfer heat away from the substrate during plasma processing. For example, the heat transfer gas can be helium, or the like.

[0046] The controller 200 can preferably control operation of the liquid source to selectively vary parameters of the liquid supplied to the flow passages, and also control operation of the heat transfer gas source 150 to selectively vary parameters of the heat transfer gas supplied to the heat transfer gas passages. The controller 200 preferably can control operation of the liquid source 100 to control the temperature and/or flow rate of liquid supplied to the flow passages by the liquid source, and control operation of the heat transfer gas source 150 to control the flow rate and/or pressure of heat transfer gas supplied to the interface portion, to achieve a desired temperature at the exposed surface.

[0047] The controller 200 preferably receives input signals from one or more temperature sensors (not shown) positioned in the substrate support 40 to measure temperature at one or more selected locations of the substrate support 40 and/or on the substrate (e.g., at the backside). For example, temperature sensors can be disposed to measure temperature at locations proximate the exposed surface of the electrostatic chuck 50. The temperature sensors preferably provide real time temperature measurements to enable feedback control of the operation of the liquid source 100, as well as control of the operation of the heat transfer gas source 150. The controller 200 can be manually operable or programmed to automatically control operation of the liquid source 100 and the heat transfer gas sources 150.

[0048] The substrate support 40 can be used in a plasma processing apparatus in which various plasma processing operations including plasma etching, physical vapor deposition, chemical vapor deposition (CVD), ion implantation, and/or resist removal are performed. The plasma processing operations can be performed for various substrate materials including semiconducting, dielectric and metallic materials.

[0049] The substrate support 40 can provide dynamic, close temperature control, which is useful for various vacuum semiconductor processes. For example, these characteristics are useful for accurate, step-changeable temperature control in gate and shallow trench isolation ("STI") etching processes. The substrate support 40 temperature can alternatively be ramped (e.g., linearly) to form tapering sidewalls in substrates during etching, for example. The capability to rapidly change the substrate temperature is useful in various processes, such as dielectric material etch processes, in which the high power densities that are utilized can cause rapid wafer over-temperature conditions to occur unless heat is rapidly removed from the substrate.

[0050] While the invention has been described in detail with reference to specific embodiments thereof, it will be apparent to those skilled in the art that various changes and modifications can be made, and equivalents employed, without departing from the scope of the appended claims.

What is claimed is:

1. A substrate support useful in a reaction chamber of a plasma processing apparatus, the substrate support comprising:



US006575622B2

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A

(12) **United States Patent**
Norrbakhsh et al.

(10) Patent No.: **US 6,575,622 B2**
(45) Date of Patent: **Jun. 10, 2003**

(54) **CORRECTION OF WAFER TEMPERATURE
DRIFT IN A PLASMA REACTOR BASED
UPON CONTINUOUS WAFER
TEMPERATURE MEASUREMENTS USING
AN IN-SITU WAFER TEMPERATURE
OPTICAL PROBE**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/013,183**

(22) Filed: **Dec. 7, 2001**

(65) **Prior Publication Data**

US 2002/0048311 A1 Apr. 25, 2002

Related U.S. Application Data

(62) Division of application No. 09/547,359, filed on Apr. 11,
2000, now Pat. No. 6,353,210.

(51) Int. Cl.⁷ **G01K 1/14; H05B 1/00;
G01J 5/08**

(52) U.S. Cl. **374/141; 374/131; 374/66;
219/497**

(58) Field of Search **374/131, 141,
374/161, 132, 12, 130, 133, 124, 126, 128;
219/497, 390, 444.1, 121.43; 392/416**

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Primary Examiner—Diego Gutierrez

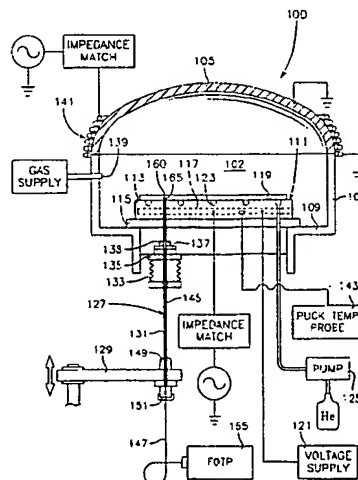
Assistant Examiner—Gail Verbitsky

(74) Attorney, Agent, or Firm—Robert M. Wallace; Joseph
Bach

(57) **ABSTRACT**

The invention solves the problem of continuously monitoring wafer temperature during processing using an optical or fluoro-optical temperature sensor including an optical fiber having an end next to and facing the backside of the wafer. This optical fiber is accommodated without disturbing plasma processing by providing in one of the wafer lift pins an axial void through which the optical fiber passes. The end of the fiber facing the wafer backside is coincident with the end of the hollow lift pin. The other end is coupled via an "external" optical fiber to temperature probe electronics external of the reactor chamber. The invention uses direct wafer temperature measurements with a test wafer to establish a data base of wafer temperature behavior as a function of coolant pressure and a data base of wafer temperature behavior as a function of wafer support or "puck" temperature. These data bases are then employed during processing of a production wafer to control coolant pressure in such a manner as to minimize wafer temperature deviation from the desired temperature.

4 Claims, 5 Drawing Sheets



*use of Helium pressure
to control Moxer T₀*



US006703592B2

Cite

(12) **United States Patent**
Van Bilsen

(10) Patent No.: **US 6,703,592 B2**
(45) Date of Patent: **Mar. 9, 2004**

(54) **SYSTEM OF CONTROLLING THE
TEMPERATURE OF A PROCESSING
CHAMBER**

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(US)**

(73) Assignee: **ASM America, Inc., Phoenix, AZ (US)**

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/309,383**

(22) Filed: **Dec. 2, 2002**

(65) **Prior Publication Data**

US 2003/0080112 A1 May 1, 2003

Related U.S. Application Data

(63) Continuation of application No. 09/739,863, filed on Dec.
18, 2000, now Pat. No. 6,507,007, which is a continuation
of application No. 09/495,765, filed on Feb. 1, 2000, now
Pat. No. 6,191,399.

(51) Int. Cl.⁷ **H05B 1/02**

(52) U.S. Cl. **219/497; 219/497; 219/501;
219/505; 219/494; 219/486; 392/416; 392/418;
374/1; 374/102; 374/103; 118/724; 118/725**

(58) Field of Search **219/497, 501,
219/505, 494, 486; 392/416, 418; 374/1,
102, 103; 118/724, 725**

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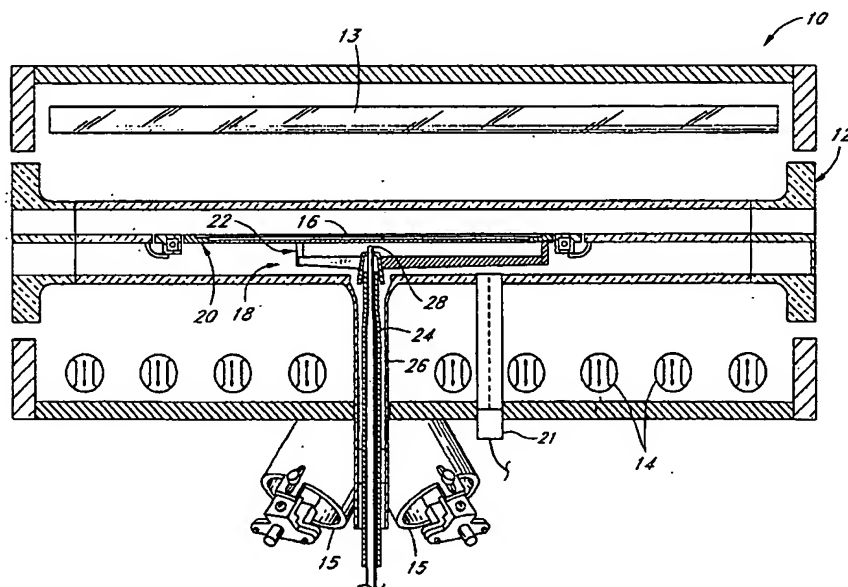
Primary Examiner—Mark Paschall

(74) *Attorney, Agent, or Firm*—Knobbe, Martens, Olson &
Bear, LLP

(57) **ABSTRACT**

A CVD processing reactor employs a pyrometer to control
temperature ramping. The pyrometer is calibrated between
wafer processing by using a thermocouple that senses tem-
perature during a steady state portion of a processing opera-
tion.

31 Claims, 5 Drawing Sheets





US006106148A

United States Patent [19]

Moslehi et al.

[11] Patent Number: 6,106,148
[45] Date of Patent: Aug. 22, 2000

[54] APPARATUS INCLUDING INTEGRAL ACTUATOR WITH CONTROL FOR AUTOMATED CALIBRATION OF TEMPERATURE SENSORS IN RAPID THERMAL PROCESSING EQUIPMENT

[75] Inventors: Mehrdad M. Moslehi, Los Altos; Yong Jin Lee, San Jose, both of Calif.

[73] Assignee: CVC, Inc.

[21] Appl. No.: 09/344,419

[22] Filed: Jun. 25, 1999

Related U.S. Application Data

- [62] Division of application No. 08/680,244, Jul. 10, 1996, Pat. No. 6,004,029.
[60] Provisional application No. 60/000,989, Jul. 10, 1995.
[51] Int. Cl.⁷ G01K 15/00; H01L 21/02; F27D 11/00
[52] U.S. Cl. 374/1; 374/141; 392/416; 219/390; 427/521; 427/557; 438/796
[58] Field of Search 374/1, 141; 392/416; 219/390; 427/521, 557; 438/796

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Primary Examiner—Diego Gutierrez

Assistant Examiner—Stanley J. Pruchnic, Jr.

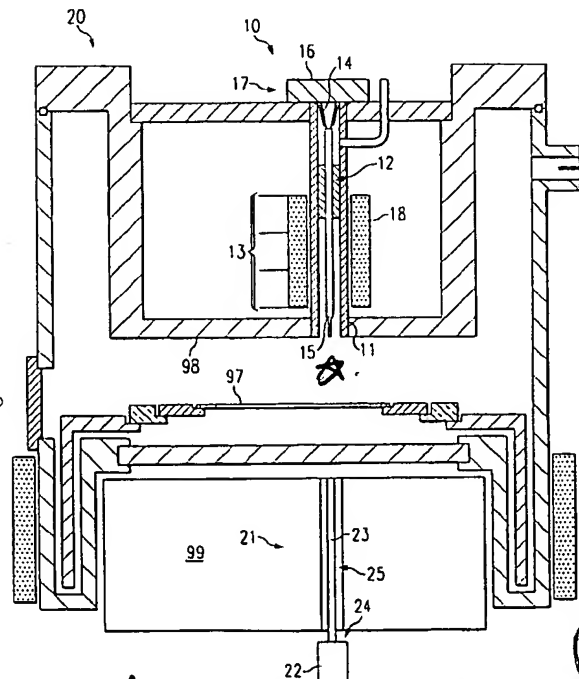
Attorney, Agent, or Firm—Gray Cary Ware & Freidenrich LLP

[57]

ABSTRACT

This invention presents an automatic calibration system and method for calibration of a substrate temperature sensor in a thermal processing equipment, such as a rapid thermal processing system. The calibration system includes a temperature-sensitive probe associated with the substrate temperature sensor to calibrate the substrate temperature sensor and an actuator to position the temperature-sensitive probe relative to the substrate during a calibration cycle. The actuator and temperature-sensitive probe of the automatic calibration system can be incorporated into the thermal processing equipment in order to maintain the thermal processing equipment cleanliness and integrity during a calibration cycle, and to allow rapid automated calibration. In the preferred embodiment of this invention, the temperature-sensitive probe and its actuator are implemented in the gas showerhead assembly of a rapid thermal processing system.

50 Claims, 5 Drawing Sheets





US005848842A

**United States Patent** [19][11] **Patent Number:** **5,848,842****Peuse et al.**[45] **Date of Patent:** **Dec. 15, 1998****[54] METHOD OF CALIBRATING A
TEMPERATURE MEASUREMENT SYSTEM****[75] Inventors:** **Bruce W. Peuse**, San Carlos; **Gary E. Miner**, Newark; **Mark Yam**, San Jose, all of Calif.**[73] Assignee:** **Applied Materials, Inc.**, Santa Clara, Calif.**[21] Appl. No.:** **650,744****[22] Filed:** **May 20, 1996****Related U.S. Application Data****[62]** Division of Ser. No. 359,302, Dec. 19, 1994, Pat. No. 5,660,472.**[51] Int. Cl.⁶** **G01K 51/00****[52] U.S. Cl.** **374/1; 374/2****[58] Field of Search** **374/1, 2, 126, 374/128****[56] References Cited****U.S. PATENT DOCUMENTS**

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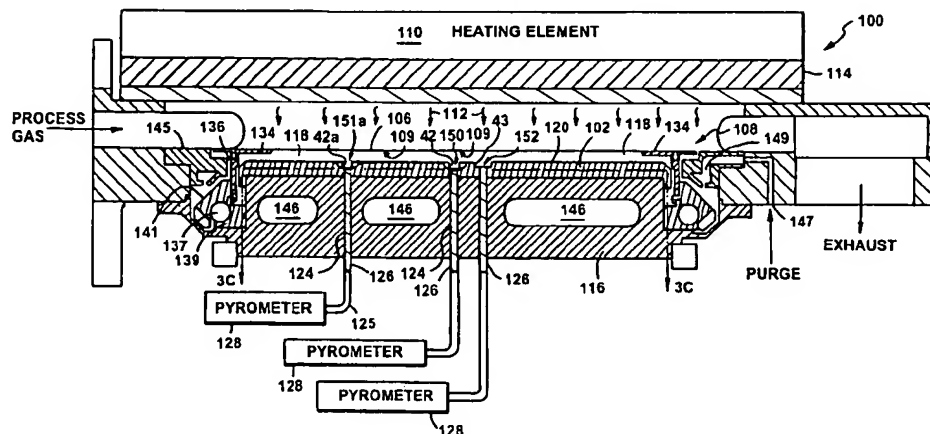
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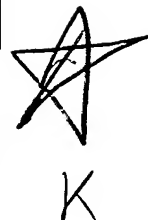
Primary Examiner—William A. Cuchlinski, Jr.*Assistant Examiner*—Andrew Hirshfeld*Attorney, Agent, or Firm*—Fish & Richardson P.C.**[57] ABSTRACT**

A method of calibrating a temperature measurement system including the steps of heating a first substrate having a high emissivity value to a first process temperature; while the first substrate is at the first process temperature, calibrating a first probe and a second probe to produce temperature indications from the first substrate that are substantially the same, the first probe having associated therewith a first effective reflectivity and the second probe having associated therewith a second effective reflectivity, the first and second effective reflectivities being different; heating a second substrate having a low emissivity value to a second process temperature, the low emissivity value being lower than the high emissivity value; with the second substrate at the second process temperature, using both the first probe and the second probe to measure the temperature of the second substrate, the first probe producing a first temperature indication and the second probe producing a second temperature indication different from the first temperature indication; measuring a sensitivity of the temperature indication produced by the first probe to changes in substrate emissivity; and by using the measured sensitivity and the first and second temperature indications, computing a correction factor for the first probe, the correction factor to be applied to subsequent temperature readings of the first probe to produce corrected temperature readings.

12 Claims, 12 Drawing Sheets



US006798036B2



(12) **United States Patent**
Yun

(10) **Patent No.:** **US 6,798,036 B2**
(45) **Date of Patent:** **Sep. 28, 2004**

(54) **TEMPERATURE MEASURING METHOD
AND APPARATUS IN SEMICONDUCTOR
PROCESSING APPARATUS, AND
SEMICONDUCTOR PROCESSING METHOD
AND APPARATUS**

(75) **Inventor:** **Mo Yun, Yamanashi (JP)**

(73) **Assignee:** **Tokyo Electron Limited, Tokyo (JP)**

(*) **Notice:** Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) **Appl. No.:** **10/431,528**

(22) **Filed:** **May 8, 2003**

(65) **Prior Publication Data**

US 2003/0206574 A1 Nov. 6, 2003

Related U.S. Application Data

(62) Division of application No. 09/995,769, filed on Nov. 29,
2001, now Pat. No. 6,579,731.

(30) **Foreign Application Priority Data**

Dec. 1, 2000 (JP) 2000-367071

(51) **Int. Cl.⁷** **H01L 31/058; H01L 21/66;**
H01L 21/00; G01K 15/00; G01K 17/00

(52) **U.S. Cl.** **257/467; 438/14; 438/54;**
374/2; 374/29; 374/120

(58) **Field of Search** **438/10; 374/2,**
374/29, 120, 43

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Primary Examiner—Jack Chen

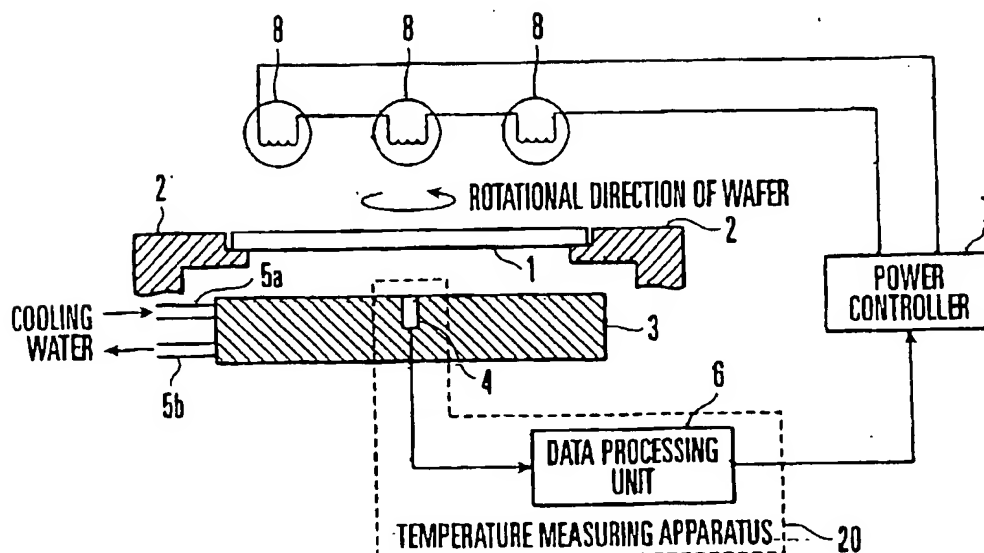
Assistant Examiner—David L. Hogans

(74) *Attorney, Agent, or Firm*—Finnegan, Henderson,
Farabow, Garrett & Dunner, L.L.P.

(57) **ABSTRACT**

A temperature measuring method for a target substrate to be thermally processed in a semiconductor processing apparatus under a predetermined process condition is provided. This method includes the steps of detecting a heat flux supplied from at least part of the target substrate and detecting a temperature of a sensor by using the sensor facing the target substrate, and calculating a temperature of the target substrate from a parameter, including a thermal resistance between the sensor and the target substrate under the predetermined process condition, the detected heat flux, and the temperature of the sensor. The sensor is arranged opposite to heating means, through the target substrate, which heats the target substrate. The parameter may be obtained in advance by calibration.

4 Claims, 3 Drawing Sheets

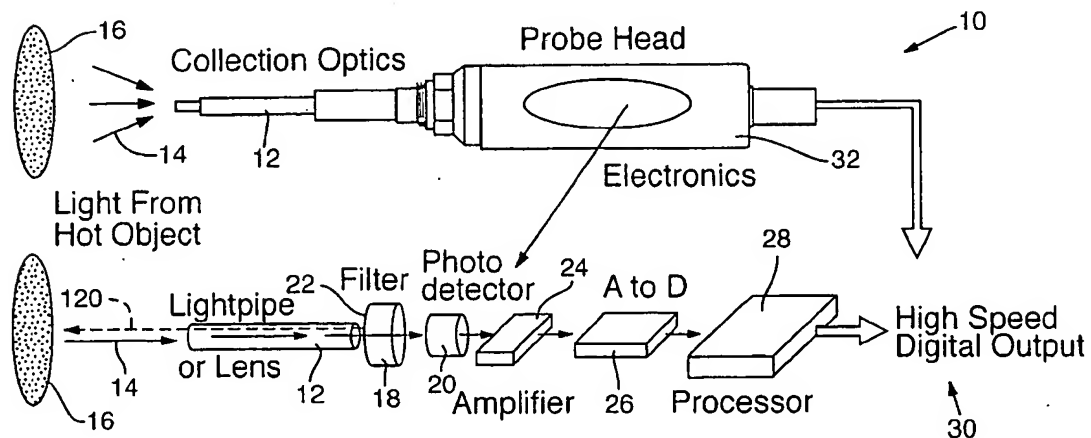




US 20030033110A1

(19) **United States**(12) **Patent Application Publication**
Schietinger et al.(10) **Pub. No.: US 2003/0033110 A1**(43) **Pub. Date: Feb. 13, 2003**(54) **WAFER TEMPERATURE MEASUREMENT
METHOD FOR PLASMA ENVIRONMENTS****Publication Classification**(51) **Int. Cl.⁷** G01K 11/30(52) **U.S. Cl.** 702/134(76) **Inventors:** Charles W. Schietinger, Milwaukie,
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PORTLAND, OR 97204 (US)(21) **Appl. No.:** 10/197,230(22) **Filed:** Jul. 16, 2002**Related U.S. Application Data**(63) Continuation-in-part of application No. 09/872,750,
filed on May 31, 2001.(60) Provisional application No. 60/209,168, filed on Jun.
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on Jun. 2, 2000. Provisional application No. 60/209,
076, filed on Jun. 2, 2000. Provisional application No.
60/217,012, filed on Jul. 10, 2000.(57) **ABSTRACT**

The temperature of a semiconductor wafer (160) is measured while undergoing processing in a plasma (168) environment. At least two pyrometers (162, 164) receive radiation from, respectively, the semiconductor wafer and the plasma in a plasma process chamber. The first pyrometer receives radiation from either the front or rear surface of the wafer, and the second pyrometer receives radiation from the plasma. Both pyrometers may be sensitive to the same radiation wavelength. A controller (170) receives signals from the first and second pyrometers and calculates a corrected wafer emission, which is employed in the Planck Equation to calculate the wafer temperature. Alternatively, both pyrometers are positioned beneath the wafer with the first pyrometer sensitive to a first wavelength where the wafer is substantially opaque to plasma radiation, and the second pyrometer is sensitive to a wavelength where the wafer is substantially transparent to plasma radiation.



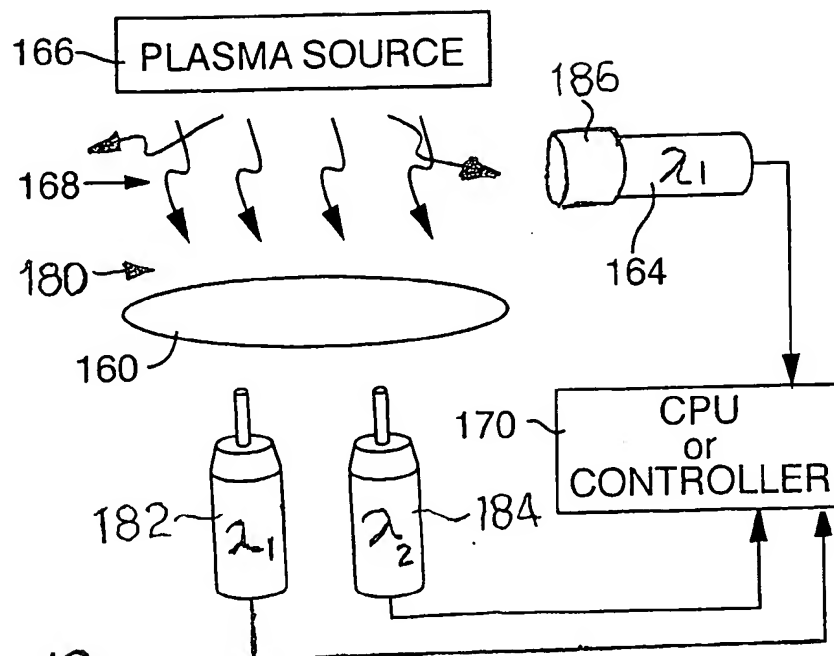


FIG. 18



US006406924B1

(12) **United States Patent**
Grimbergen et al.

(10) **Patent No.:** **US 6,406,924 B1**
(45) **Date of Patent:** **Jun. 18, 2002**

(54) **ENDPOINT DETECTION IN THE
FABRICATION OF ELECTRONIC DEVICES**

(75) Inventors: **Michael N. Grimbergen**, Redwood
City; **Thorsten B. Lill**, Sunnyvale, both
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(73) Assignee: **Applied Materials, Inc.**, Santa Clara,
CA (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/286,493**

(22) Filed: **Apr. 5, 1999**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/062,520, filed on
Apr. 17, 1998.

(51) Int. Cl.⁷ **H01L 21/00**

(52) U.S. Cl. **438/9; 156/345; 216/60;**
356/357; 438/723; 438/743

(58) Field of Search **438/9, 14, 16,**
438/723, 743; 216/56, 60; 156/345 MT;
356/357

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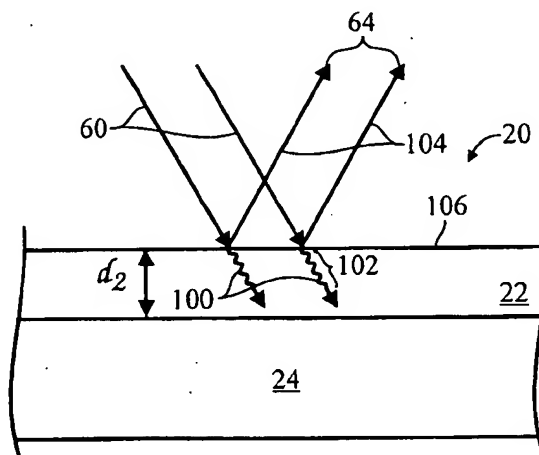
Primary Examiner—William A. Powell

(74) Attorney, Agent, or Firm—Janah & Associates

(57) **ABSTRACT**

A chamber 28 comprises a radiation source 58 capable of
emitting radiation having a wavelength that is substantially
absorbed in a predetermined pathlength in a thickness of a
layer 22 on a substrate, and a radiation detector 62 adapted to
detect the radiation. The radiation is substantially
absorbed in a first thickness of the layer 22, and after at least
partial processing of the layer 22, is at least partially
transmitted through a second thickness of the layer 22 and
reflected by one or more underlayers 24 of the substrate 20.

96 Claims, 11 Drawing Sheets





US006299346B1

Steve

(12) **United States Patent**
Ish-Shalom et al.

(10) **Patent No.:** **US 6,299,346 B1**
(45) **Date of Patent:** **Oct. 9, 2001**

(54) **ACTIVE PYROMETRY WITH EMISSIVITY
EXTRAPOLATION AND COMPENSATION**

(75) **Inventors:** Yaron Ish-Shalom, Kiryat Tivon (IL);
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(73) **Assignee:** C. I. Systems LTD, Migdal Haemek
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(*) **Notice:** Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

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(21) **Appl. No.:** 09/521,113

(22) **Filed:** Mar. 7, 2000

Related U.S. Application Data

(60) Provisional application No. 60/123,371, filed on Mar. 8,
1999.

(51) **Int. Cl.:** G01K 5/06

(52) **U.S. Cl.:** 374/126; 374/127; 374/128;
374/130; 374/134; 374/131

(58) **Field of Search:** 374/134, 126,
374/128, 130, 132, 131, 127, 121

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Primary Examiner—Diego Gutierrez

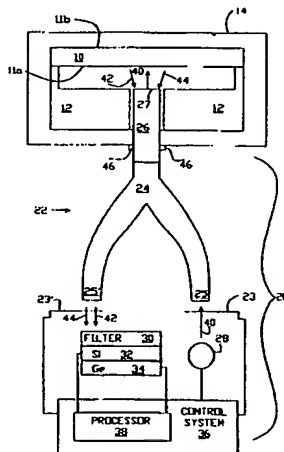
Assistant Examiner—Gail Verbitsky

(74) *Attorney, Agent, or Firm*—Mark M. Friedman

(57) **ABSTRACT**

A method and apparatus for active pyrometric measurement
of the temperature of a body whose emissivity varies with
wavelength. The emissivity is inferred from reflectivity
measured at two wavelengths in an irradiation wavelength
band and extrapolated to a wavelength in an emission
wavelength band. The extrapolated emissivity is used to
correct a blackbody estimate of the temperature of the body
in the emission wavelength band. The extrapolation, being
temperature-dependent, is done iteratively. Both reflectivity
and emission measurements are performed via a common
optical head that is shaped, and is positioned relative to the
body, so that the optical head has a sufficiently large solid
angle of acceptance that the measured temperature is inde-
pendent of superficial roughness of the body.

35 Claims, 6 Drawing Sheets



US-PAT-NO: 5823681

DOCUMENT-IDENTIFIER: US 5

TITLE: Multipoint temp
semiconductor waf

U.S. Patent

Oct. 20, 1998

Sheet 2 of 7

5,823,681

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Current US Class - CLAS (3):
392

Current US Cross Reference Cla
(2):
374/1

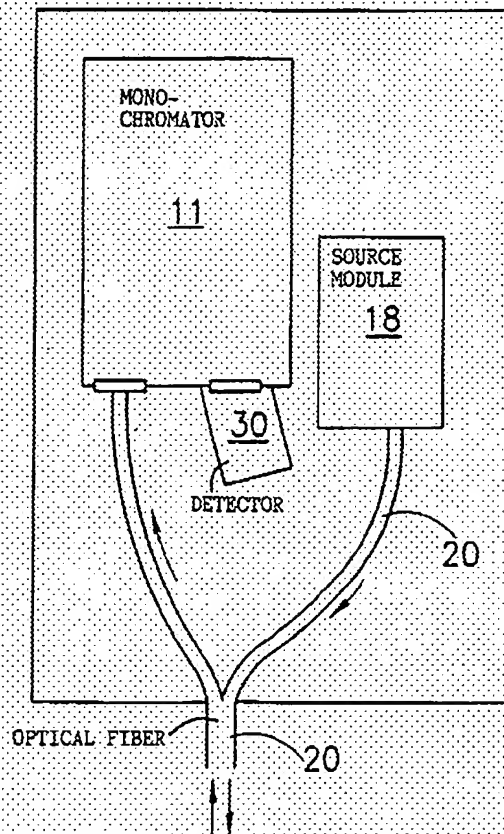


FIG. 2

c)

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BACKGROUND OF THE INVENTION

temperature than other parts of the wafer, i.e., it disturbs the temperature profile on the substrate. Second, at high temperatures (e.g., 1000° C. as is commonly found in RTP processes) the joint between the wafer and thermocouple tends to degrade, so that after four or five uses the thermocouple readings become unreliable. Because of these shortcomings, this calibration technique cannot really guarantee pyrometer accuracy that is better than ten to fifteen % C.

In addition, there are difficulties associated with placing a thermocoupled substrate inside the chamber and making electrical connection to the thermocouple.

In rapid thermal processing (RTP), a substrate is heated quickly to a high temperature, such as 1200°C, to perform a fabrication step such as sintering, cleaning, chemical vapor deposition, oxidation, or nitridation. Particularly given the submicron dimensions of current devices, to obtain high yields and process reliability, the temperature of the substrate must be precisely controlled during these thermal processing steps. For example, to fabricate a dielectric layer 50–80 Å thick with a uniformity of ± 2 Å, which is typical of requirements in current device structures, the temperature in successive processing runs cannot vary by more than a few °C from the target temperature. To achieve this level of temperature control, the temperature of the substrate is measured in real time and in situ.

Optical pyrometry is a technology that is used to measure substrate temperatures in RTP systems. An optical pyrometer using an optical probe samples the emitted radiation intensity from the substrate, and computes the temperature of the substrate based on the spectral emissivity of the substrate and the ideal blackbody radiation-temperature relationship.

When the system is first set up, the optical probe must be calibrated so that it produces a correct temperature reading when exposed to the radiation coming from the heated substrate. In addition, during repeated use, the temperature sensed by the probe might change over time and thus it will be necessary to recalibrate the probe or at least detect the change that has occurred so that corrective action can be taken. For example, the light pipe which is used to sample the radiation being emitted from the substrate as it is being heated, may become dirty or chipped, connections along the optical column transferring the sampled light to the pyrometer may loosen, or the electronic components in the pyrometer may "drift".

A commonly used method of calibrating the pyrometer is to use a special substrate or vefier in the chamber. The special substrate, which can be purchased from commercial sources, has a previously measured, known emissivity and it has an "embedded" thermocouple which is attached to the substrate with a ceramic material. When the substrate is heated, its actual temperature is indicated by the thermocouple. Since the substrate's emissivity is known, the radiation that is actually emitted by the substrate can be easily calculated by multiplying the intensity of radiation that would be expected from by an ideal black body that is at the predetermined temperature times the emissivity of the substrate. This is the radiation level that will be sampled by the optical probe of the pyrometer. The pyrometer is adjusted so that it produces a temperature reading that corresponds to the actual temperature.

Unfortunately, this method has drawbacks. The actual temperature of the substrate may in fact be different than the temperature measured by the thermocouple. First, the presence of the embedded thermocouple and the ceramic material causes the area with the thermocouple to have a different

In general, in one aspect, the invention features an apparatus for calibrating a temperature probe (e.g., a pyrometer). In the invention, a light emitting diode is held in a cavity of a calibration instrument and positioned to emit light through an aperture into an input end of the temperature probe. The calibration instrument emits light having a predetermined intensity. There is an indicia indicating a black-body temperature from that the light from the calibration instrument simulates.

In general, in another aspect, the invention features a method for calibrating a temperature probe. In the method, a stable light of a predetermined intensity shines from a calibration instrument into an input end of the temperature probe. The stable light simulates radiation from a black body at a temperature T_0 . The temperature probe is used to produce a temperature reading T_1 in response to the light. The difference between T_0 and T_1 is used to generate corrected measurements from the temperature probe during compressing within the thermal processing system.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe inside a thermal processing chamber. In the apparatus, an alignment tool has a light source having a stable intensity. The light source is held in a cavity and positioned to emit light through an aperture during calibration. A first alignment structure of the alignment tool engages a corresponding first alignment feature of the chamber. The aperture is located in a position relative to the first alignment structure so that during calibration the aperture is aligned with an input of the temperature probe.

Implementations of the invention may include the following features. The first alignment structure may comprise a pin and the first alignment feature may comprise a pinhole in a reflector plate in the chamber and located in proximity to the input end of the probe. The first alignment structure may comprise a projection adapted to fit a lift pin hole in a reflector plate in the chamber. The cavity and aperture may be located in a body and the body may include a second alignment structure to engage a corresponding second alignment feature of the alignment tool. The body may be removable from the cavity. The body may be cylindrical, and the second alignment feature may comprise a cylindrical conduit having an annular lip. The alignment tool may be a disk and the second alignment feature may comprise a conduit through the disk.

In general, in another aspect, the invention features an apparatus for calibrating a temperature probe outside a thermal processing chamber. The apparatus features an alignment tool having a cavity and an aperture leading thereon. The alignment tool has an alignment structure to engage an input end of the probe. A light source having a stable intensity is held in the cavity and positioned to emit

Details Text Image HTML

6,086,245



Bandpass optical filter 52

between semiconductor device 12 and bakeplate 20 that is 1%, preferably less than 0.1% of the area of first major surface 22 underlying semiconductor device 12. According to one specific example of a protuberance distribution as shown in FIG. 1d, six tubular protuberances 56 having a height of 150 micrometers, an outside diameter of about 1.6 mm, and an inside diameter of about 0.8 mm are arranged in two triangular patterns positioned at two different radii 58 and 60 from the center of bakeplate 20. With this approach, the total contact area between semiconductor device 12 and bakeplate 20 is so small as to be negligible, yet semiconductor device 12 (and annular member 40 if present) is adequately supported. As another example, a large number of protuberances 56 can be formed in an array over the entire surface 22, e.g., as a triangular pattern in which adjacent protuberances 56 are about 4 mm to 6 mm apart. In such an array, individual protuberances 56 are typically 0.1 mm to 0.5 mm, preferably about 0.2 mm to 0.3 mm, in diameter.

Bakeplate 20 may optionally be provided with one or more flow channels 38 in order to provide fluid communication gap 62 between bakeplate 20 and semiconductor device 12. Gap 62 may be filled with a gas such as ordinary air or a more conductive gas if it is desired to enhance the thermal conductivity between bakeplate 20 and semiconductor device 12. For example, helium gas is approximately seven times more conductive than air. Introducing a gas into gap 62 might also help reduce the tendency of semiconductor device edge 13 to overheat relative to other portions of semiconductor device 12. Alternatively, in the presence of an appropriate seal between semiconductor device 12 and bakeplate 20, gap 62 may be used to pull a slight vacuum, e.g., a vacuum on the order of 3000 Pa to 14,000 Pa, against wafer 12 in order to help hold wafer 12 in position. For example, an annular shaped protuberance (not shown) could be provided on bakeplate 20 proximal to edge 13 to help form such a seal.

Still referring to FIGS. 1a, 1b, and 1c, the temperature of semiconductor device 12 is desirably monitored directly or indirectly during baking and chilling operations so that the heat output of bakeplate 20 can be controlled using a suitable feedback control methodology, such as PID control. According to the direct approach for monitoring wafer temperature, a suitable temperature sensor (not shown) can be attached directly to semiconductor device 12. However, for high volume production applications, this approach is not really practical or desirable, because the direct approach requires the additional processing steps of attaching and detaching temperature sensor(s) to a semiconductor device every time a new semiconductor device is to be inserted into apparatus 10 for processing. Additionally, wafers typically support sensitive componentry that could be adversely affected by contact with a temperature sensor.

Accordingly, it is much more desirable to monitor the temperature of semiconductor device 12 indirectly by attaching a suitable temperature sensor to annular member 40, particularly when the thermal capacity of annular member 40 is matched to that of wafer 12 as discussed above. Under such circumstances, the actual temperature of the top surface of semiconductor device 12 substantially corresponds to the temperature of the top surface of annular member 40 at substantially all times during baking and/or chilling, even during temperature ramps. Indeed, the difference in temperature between the top surface of annular member 40 and the top surface of semiconductor device 12 is substantially constant and more preferably negligible, as a practical matter. Accordingly, when indirectly monitoring the temperature of the top surface of semiconductor device

12 using a temperature sensor coupled to the top surface of annular member 40, a simple correction, if needed, can be applied to the measured temperature in order to account for the temperature difference, if any, between the top surfaces of semiconductor device 12 and annular member 40.

The temperature sensor to be used in the present invention may be any suitable temperature sensor that is capable of sensing temperature at rapid intervals with stability and consistency over long periods of time. A variety of suitable temperature sensing devices are known of which a resistive thin-film (RTD) sensor is most preferred. Several suitable types are available from a variety of commercial sources. As one example, a suitable thin-film RTD sensor is commercially available under the trade designation 517422 PDX40A from Minco Products, Inc., Minneapolis, Minn. This sensor incorporates a platinum wire having a diameter of about 50 micrometers encased in a "KAPTON" brand polyamide resin layer having a thickness of about 100 micrometers (i.e., the encased wire has an overall diameter of about 250 micrometers). The RTD sensor may be bonded into the desired position using a suitable temperature resistant adhesive such as a polyamide resin, a polyimide resin, a polyimideamide resin, a silicone resin, an epoxy resin, microtextured polytetrafluoroethylene, combinations of these, or the like.

As an alternative to buying an RTD temperature sensor, an RTD temperature sensor may be constructed in situ, or constructed in-house and then subsequently bonded into position, from an electroresistive material with RTD characteristics using any suitable formation technique known in the art such as a sputter-etching process. For example, to form an RTD sensor in situ, a layer of a suitable electroresistive metal such as platinum may be deposited at the desired position and then etched to form an RTD temperature sensor. A layer of insulation is desirably deposited between the sensor and the component to which the sensor is attached. The layer of insulation may comprise any insulating material of the type conventionally used in the microelectronics industry, including polytetrafluoroethylene, polyamide, polyimide, polyamideimide, silicon dioxide, silicon nitride, combinations of these, and the like.

In some applications, an RTD sensor used by itself may not have the requisite agility needed to provide meaningful control of wafer temperature. In those situations, a particularly preferred temperature sensor is a hybrid sensor system including a combination of a relatively slow and stable first temperature sensing device (preferably an RTD sensor) and a relatively fast and unstable second sensor device (preferably a thermocouple). The fast/unstable second sensor device is used to sense temperature of wafer 12 with greater speed, while temperature measurements sensed by the slow/stable first sensor device are used to calibrate the second sensor automatically on-line so that the second sensor measurements remain accurate and reliable over time.

The concept of using the hybrid temperature sensor is based upon the appreciation that thermocouples can sense temperature at rates as fast as 1000 to 2000 Hz, yet tend to have relatively poor temperature sensing stability over time. On the other hand, although a typical RTD temperature sensor might have a lower sensing speed, e.g., temperature sensing capabilities of only up to about 10 Hz, RTD sensors generally have excellent temperature sensing stability over long periods of time. Thus, by using the RTD sensor to calibrate the thermocouple automatically on-line, the hybrid sensor system obtains the benefits of both kinds of sensing

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United States Patent [19]

Pecot et al.

[11] Patent Number: 4,854,727

[45] Date of Patent: Aug. 8, 1989

[54] EMISSIVITY CALIBRATION APPARATUS AND METHOD

[75] Inventors: Michel Pecot, Palo Alto; Jaim Nulman, Sunnyvale, both of Calif.

[73] Assignee: AG Processing Technologies, Inc., Sunnyvale, Calif.

[21] Appl. No.: 114,542

[22] Filed: Oct. 26, 1987

[51] Int. Cl.⁴ G01N 3/60; G01N 17/00

[52] U.S. Cl. 374/57; 374/12; 374/121

[58] Field of Search 374/134, 132, 130, 131, 374/12, 13, 15, 112, 115, 121, 170, 179, 204, 57, 120, 137

[56] References Cited

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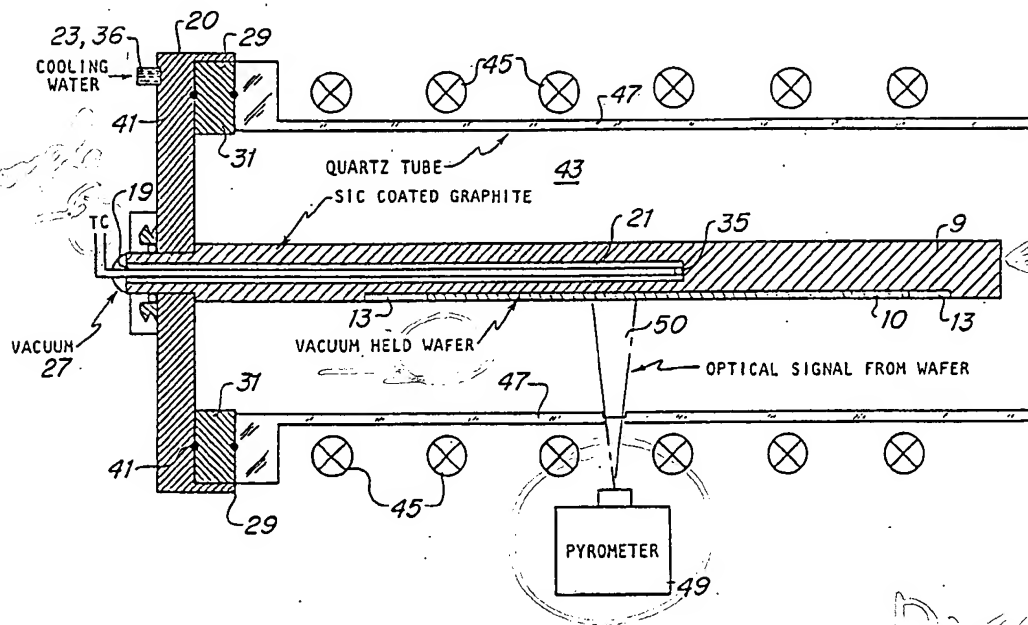
4,698,507 10/1987 Tator et al. 374/57

Primary Examiner—Roy N. Envall, Jr.
Attorney, Agent, or Firm—A. C. Smith

[57] ABSTRACT

An improved method and apparatus are disclosed for calibrating the emissivity characteristics of a semiconductor wafer within a processing chamber by supporting a sample wafer on a graphite susceptor within the chamber and by comparing the temperature measured within the susceptor in close proximity to the center of the wafer with the temperature measured by the emission of radiation from the surface of the wafer through the walls of the processing chamber. Temperature measurements subsequently made from the radiation emitted from the surface of similar wafers are corrected with reference to the measurement made of the temperature within the susceptor on the sample wafer.

7 Claims, 3 Drawing Sheets





US005823681A

United States Patent

[19]

[11] Patent Number: 5,823,681

Cabib et al.

[45] Date of Patent: Oct. 20, 1998

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[54] MULTIPOINT TEMPERATURE
MONITORING APPARATUS FOR
SEMICONDUCTOR WAFERS DURING
PROCESSING

[75] Inventors: Dario Cabib, Timrat; Robert A.
Buckwald, Ramat Ishay; Michael E.
Adel, Zichron Yakov, all of Israel

[73] Assignee: C.I. Systems (Israel) Ltd., Migdal
Hacmck, Israel

[21] Appl. No.: 604,997

[22] PCT Filed: Jul. 12, 1995

[86] PCT No.: PCT/US95/08521

§ 371 Date: Feb. 29, 1996

§ 102(e) Date: Feb. 29, 1996

[87] PCT Pub. No.: WO96/04534

PCT Pub. Date: Feb. 15, 1996

[30] Foreign Application Priority Data

Aug. 2, 1994 [IL] Israel 110549

[51] Int. Cl.⁶ G01J 5/08; G01J 5/02;
G01J 5/28; G01J 5/62; G01J 5/06

[52] U.S. Cl. 374/126; 374/130; 374/128;
374/133; 374/131; 374/1; 392/416; 118/724

[58] Field of Search 374/1, 9, 126,
374/131, 133, 128, 130; 356/44; 250/338.1;
392/416; 219/390, 405, 411; 118/50.1, 724

[56] References Cited

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Primary Examiner—Diego F. F. Gutierrez

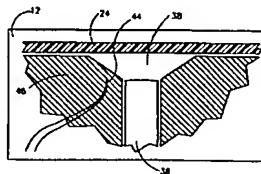
Attorney, Agent, or Firm—Mark M. Friedman

[57] ABSTRACT

An emissivity compensating non-contact system for measuring the temperature of a semiconductor wafer. The system includes a semiconductor wafer emissivity compensation station for measuring the reflectivity of the wafer at discrete wavelengths to yield wafer emissivity in specific wavelength bands. The system further includes a measurement probe which is optically coupled to a semiconductor process chamber. The probe senses wafer self emission using one or more optical detectors and a light modulator. A background temperature determining mechanism independently senses the temperature of a source of background radiation. Finally, a mechanism calculates the temperature of the semiconductor wafer based on the reflectivity, self-emission and background temperature.

21 Claims, 7 Drawing Sheets

~~COMP~~
COMPACT CO. 4

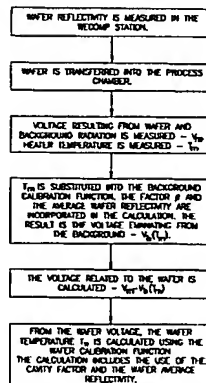


MONOCHROMATOR (FIG 2)
col 4: 25-28

WAFER

BANDPASS OPTICAL FILTER (A5)
col 3: 58

Known Radiation
(See "Problem" 4.2)
col 5: 1-



GAS FLOW (FIG 7A)

FOR EQUILIBRATION
col 6: 12-15



US006062729A

United States Patent [19]

Ni et al.

[11] Patent Number: 6,062,729

[45] Date of Patent: May 16, 2000

[54] **RAPID IR TRANSMISSION THERMOMETRY FOR WAFER TEMPERATURE SENSING**[75] Inventors: **Tuqlang Ni**, Fremont; **Michael Barnes**, San Francisco, both of Calif.[73] Assignee: **Lam Research Corporation**, Fremont, Calif.

[21] Appl. No.: 09/050,897

[22] Filed: Mar. 31, 1998

[51] Int. Cl.⁷ G01J 5/10; G01N 25/00

[52] U.S. Cl. 374/161; 374/121; 374/124; 374/126; 374/128; 374/131; 374/137

[58] Field of Search 374/121, 127, 374/130, 131, 161, 2, 128, 124, 126

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Primary Examiner—G. Bradley Bennett

Assistant Examiner—Gail Verbitsky

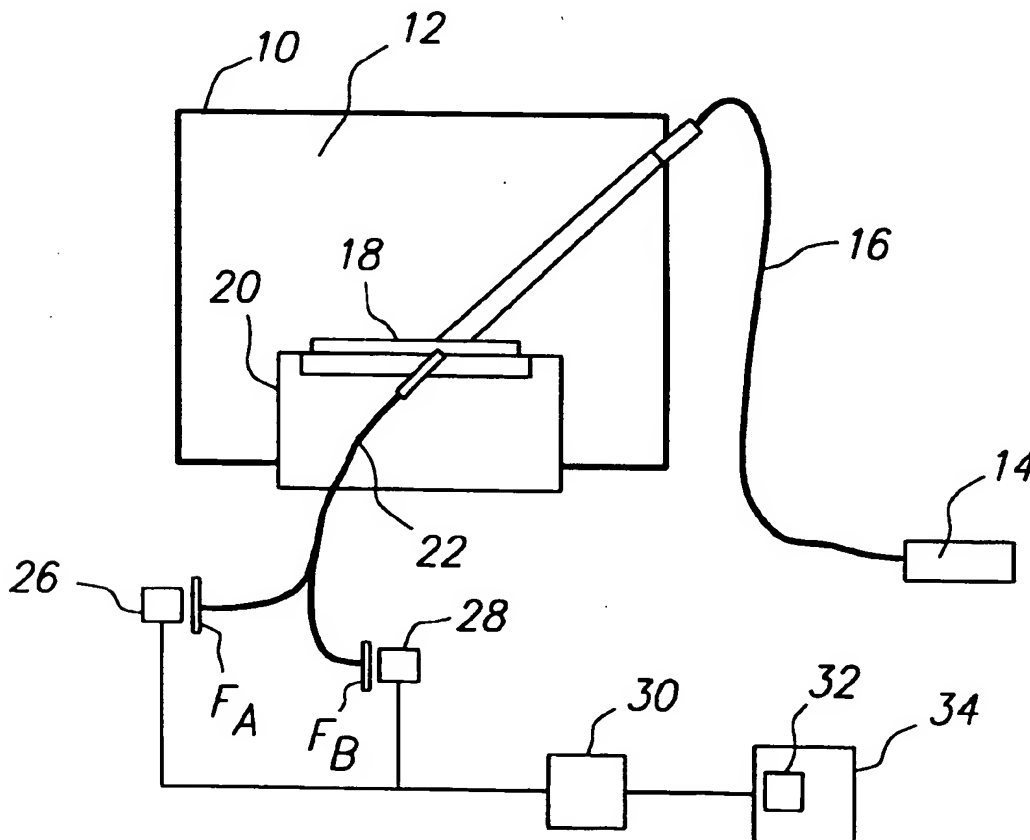
Attorney, Agent, or Firm—Burns, Doane, Swecker & Mathis, L.L.P.

[57]

ABSTRACT

A method and apparatus for measuring the temperature of an object, such as a substrate, during processing. The object is illuminated by a light source. Infrared light that is transmitted through the object is then collected and transmitted to a photodiode. The amount of light transmitted through the substrate varies as a function of substrate temperature. The photodiode generates a signal in response to the light transmitted to the photodiode and an analyzing device generates a real-time temperature reading based on the signal. The photodiode may include at least one silicon photodiode or a plurality of photodiodes made from germanium or indium/gallium/arsenide.

21 Claims, 3 Drawing Sheets



IN A
PLASMA
PROCESSING
SYSTEM

Related
Temperature
Measurement
Devices

BAW Pm,
IR TRANSM.



US005388909A

United States Patent [19]

Johnson et al.

[11] Patent Number: 5,388,909

[45] Date of Patent: Feb. 14, 1995

[54] OPTICAL APPARATUS AND METHOD FOR MEASURING TEMPERATURE OF A SUBSTRATE MATERIAL WITH A TEMPERATURE DEPENDENT BAND GAP

[76] Inventors: Shane R. Johnson; Christian Lavoie, both of 2626 Tennis Crescent, Vancouver, B. C., Canada, V6T 2E1; Mark K. Nissen, 215 - 2190 West 7th Avenue, Vancouver, B. C., Canada, V6K 4K7; J. Thomas Tiedje, 1752 Westbrook Crescent, Vancouver, B. C., Canada, V6T 1W1

[21] Appl. No.: 121,521

[22] Filed: Sep. 16, 1993

[51] Int. Cl.⁶ G01K 11/00; G01J 5/48

[52] U.S. Cl. 374/161; 374/120; 356/44

[58] Field of Search 374/120, 161, 131; 356/44

[56] References Cited

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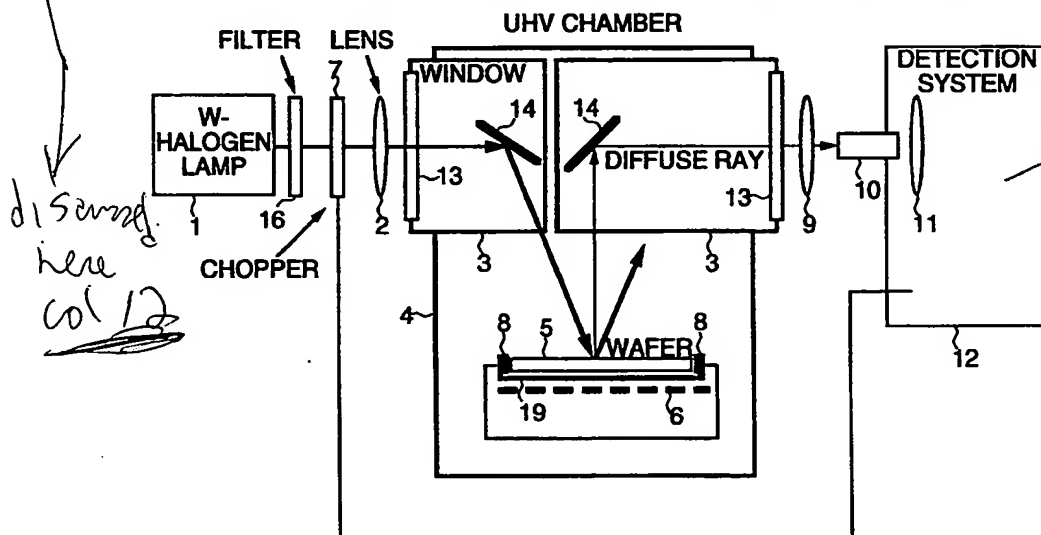
Primary Examiner—Diego F. F. Gutierrez.

Attorney, Agent, or Firm—Oyen Wiggs Green & Mutala

[57] ABSTRACT

An optical method and apparatus for measuring the temperature of a substrate material with a temperature dependent bandgap. The substrate is illuminated with a broad spectrum lamp and the bandgap is determined from the spectrum of the diffusely scattered light. The spectrum of the light from the lamp is sufficiently broad that it covers the spectral range above and below the bandgap of the substrate. Wavelengths corresponding to photon energies less than the bandgap of the substrate are transmitted through the substrate and are reflected from the back surface of the substrate as well as from the front surface while the wavelengths corresponding to photon energies larger than the bandgap are reflected only from the front surface. If the front surface is polished the front surface reflection will be specular while if the back surface is rough the reflection from the back surface will be non-specular. The back surface reflection is detected with a detector in a non-specular location. From the wavelength of the onset of the non-specular reflection the bandgap can be determined which gives the temperature. The temperature is determined from the knee in the diffuse reflectance spectrum near the bandgap.

17 Claims, 18 Drawing Sheets



United States Patent [19]

Poenisch et al.

[11] Patent Number: 5,021,980

[45] Date of Patent: Jun. 4, 1991

[54] REMOTE MEASUREMENT OF TEMPERATURE

[75] Inventors: Paul Poenisch, Santa Clara; Keith Hansen, San Jose, both of Calif.

[73] Assignee: LSI Logic Corporation, Milpitas, Calif.

[21] Appl. No.: 313,577

[22] Filed: Feb. 21, 1989

[51] Int. Cl.⁵ G06F 15/42; G06F 15/46; G06F 15/20; G01N 25/00

[52] U.S. Cl. 364/557; 364/550; 374/9; 374/120

[58] Field of Search 374/9, 100, 109, 126, 374/161, 120; 356/43, 45, 51, 320; 364/525, 550, 557

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Primary Examiner—Kevin J. Teska

Attorney, Agent, or Firm—Skjerven, Morrill, MacPherson, Franklin & Friel

[57]

ABSTRACT

A method for determination of the true temperature T and true radiative emissivity of a body at temperature T, using measurements of total energy radiated by the body in two or more adjacent wave length ranges $\lambda_1 \leq \lambda \leq \lambda_2$ and $\lambda_3 \leq \lambda \leq \lambda_4$; the wave length ranges may partially overlap or may be adjacent but non-overlapping.

6 Claims, 3 Drawing Sheets

